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- M'Horsell Douglas 955117- Final Volume III

(NASA-CR-162374) PHASE 1 OF THE FIRST SMALL N79-33578
POWER SYSTEM EXPERIMENT (ENGINEERING
EXPERIMENT NO. 1). VOLUME 3: EXPERIMENTAL
SYSTEM DESCRIPTIONS Final Report Unclas
(McDonnell-Douglas Astronautics Co.) 361 p G3/44 38932



## PHASE I OF THE FIRST SMALL POWER SYSTEM EXPERIMENT (ENGINEERING EXPERIMENT NO. 1)

Final Technical Report Volume III - Experimental System Descriptions

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

MCDONNELL DOUGLAS

CORPORATION



### PHASE I OF THE FIRST SMALL POWER SYSTEM EXPERIMENT (ENGINEERING EXPERIMENT NO. 1)

Final Technical Report
Volume III — Experimental System Descriptions

**MAY 1979** 

MDC G7833

APPROVED BY: 7 DR. A. J. HOLL

PROGRAM MANAGER

PREPARED FOR:

CALIFORNIA INSTITUTE OF TECHNOLOGY JET PROPULSION LABORATORY 4800 OAK GROVE BLVD PASADENA, CALIF. 91103 CONTRACT JPL NO. 955117 (NAS7-100, TASK ORDER NO. RD-152)

OF POOR QUALITY

#### PREFACE

This document constitutes the McDonnell Douglas Astronautics Company (MDAC) final technical report for Phase I of the First Small Power System Experiment (Engineering Experiment No. 1). Phase I is an investigation of various system concepts that will allow the selection of the most appropriate system or systems for the first small solar power system application. This 10-month study is a part of the Small Power Systems Program that is being developed under the direction of the Department of Energy (DOE) and managed by the Jet Propulsion Laboratory (JPL). The final report is submitted to JPL under Contract No. 955117.

The final technical report consists of five volumes, as follows:

- Volume I Executive Summary
  - II System Concept Selection
  - III Experimental System Definitions (3.5, 4.5, and 6.5 Year Programs)
  - IV Commercial System Definition
  - V Supporting Analyses and Trade Studies

Requests for further information should be directed to the following:

- Mr. J. R. Womack, JPL Technical Manager Jet Propulsion Laboratory Pasadena, California Telephone (213) 577-9302
- Dr. R. J. Holl, MDAC Program Manager MDAC-Huntington Beach, California Telephone (714) 896-2755
- Mr. R. P. Dawson, MDAC Deputy Program Manager MDAC-Huntington Beach, California Telephone (714) 896-3080
- Mr. W. H. Scott, Manager Energy Contracts
   MDAC-Huntington Beach, California
   Telephone (714) 896-4821



### **ACKNOWLEDGMENTS**

The following personnel made significant contributions to this report:

MDAC	

C.	В.	Boehmer		Reliability/Availability Analyses
				Francisco Ottom on the T

W. L. Dreier Energy Storage and Energy Transport
Subsystems

C. R. Easton Concentrator Assembly

T. FahrnerJ. C. GrosseReceiver AssemblyPlant Control Subsystem

G. Hilliard Maintainability and Logistics Analyses

G. L. Keller Concentrator Assembly

R. H. McFee Collector Field Optics and Receiver Flux

R. T. Neher Receiver Assembly
J. H. Nourse Costing Analyses

J. E. Raetz Systems Analysis

E. J. Riel Plant Control Subsystem
E. T. Suter Energy Transport Subsystem

B. E. Tilton Systems Analysis and Power Conversion

Subsystem

### Rocketdyne

R. R. Gross Receiver Assembly Design
D. E. Vanevenhoven Collection Fluid Analysis

J. J. Vrolyk\* Receiver Assembly, Energy Storage Subsystem

### Stearns-Roger

J. Dubberly

Tower Assembly: Power Plant Equipment

Tower Assembly; Power Plant Equipment

W. R. Lang\*

Tower Assembly; Power Plant Equipment

### Energy Technology, Inc.

T. T. Kolenc\* Radial Outflow Turbine

### University of Houston Energy Laboratory

Dr. R. C. Bannerot\* Heliostat Field Analysis
Dr. L. L. Vant-Hull Heliostat Field Analysis

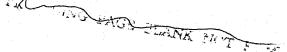
<sup>\*</sup>Subcontractor Program Manager

## CONTENTS

Section 1	PHASE	I PROGRAM INTRODUCTION	1-1
	1.1 1.2 1.3 1.4	Study Task Approach Roles and Responsibilities System Summary Experimental System Descriptions	1-3 1-4 1-5 1-5
Section 2	SUMMA	RY	2-1
Section 3	DESIG	N APPROACH	3-1
	3.1 3.2	General Groundrules General Approach	3-1 3-3
Section 4	EXPER	IMENTAL SYSTEM DESCRIPTION	4-1
	4.1	Overall System Description 4.1.1 Design and Performance	4-1
	4.2	Characteristics 4.1.2 Operational Characteristics 4.1.3 System Safety Characteristics Collector Subsystem Description -	4-19 4-19 4-48
	4.2	Concentrator Assembly 4.2.1 Design and Performance Characteristics	4-56 4-56
	4.3	4.2.2 Operational Characteristics Collector Subsystem Description -	4-68
		Receiver Assembly 4.3.1 Design and Performance	4-75
	4.4	Characteristics Tower Subsystem Characteristics	4-75 4-89
	4.5	Energy Storage Subsystem Characteristics	4-93
		4.5.1 Design and Performance Characteristics	4-93
	4.6	4.5.2 Operational Characteristics Energy Transport Subsystem	4-100
		Characteristics 4.6.1 Design and Performance	4-101
		Characteristics 4.6.2 Operational Characteristics	4-101 4-106



	4.7	Power Conversion Subsystem Characteristics 4.7.1 Design and Performance	4-118
		Characteristics	4-118
	4.8	4.7.2 Operational Characteristics Plant Control Subsystem	4-144
		Description 4.8.1 Design and Performance	4-147
		Characteristics	4-147
	4.9	4.8.2 Operational Characteristics Section 4 References	4-165 4-166
Section 5		CATION AND INSTALLATION	5-1
	5.1	Procurement, Manufacturing, and	
	5.2	Assembly Therepresents and Handling	5-3
	5.2 5.3		5-18
	· • • • • • • • • • • • • • • • • • • •	Installation	5-18
	5.4	Checkout and Adjustment	5-33
	5.5	Safety Aspects (Installation)	5-37
Section 6	MAINT	TENANCE AND REPAIR CHARACTERISTICS	6-1
	6.1	Reliability/Availability	6-3
	6.2	Inspection and Maintenance	6-6
	6.3	Maintenance Equipment and Facilities	6-28
	6.4 6.5	Safety Aspects (Maintenance) Section 6 References	6-30 6-30
Section 7	DEVEL	OPMENT REQUIREMENTS	7-1
	7.1	Development Program Objectives and Approach	7-1
	7.2	Key Technology Issues and Development	7-1
		Requirements	7-4
	7.3	Test Requirements Summary	7-17
	7.4	Section 7 References	7-19
Appendix	SYST	EM REQUIREMENTS SPECIFICATION	A-1
	A.1	Scope	A-1
	A.2		A-1
		A.2.1 Government Documents	A-2
	Λ ?	A.2.2 Non-Government Documents	A-2
	A.3	Requirements A.3.1 General System Requirements	A-4 A-4
		A.3.2 Collector Subsystem	. <u>"</u> 77
		Requirements - Concentrator	
		Assembly	A-28



Collector Subsystem	
Assembly	A-38
Collector Subsystem	
Requirement - Tower Assembly	A-47
Requirements	A-52
	A-61
	A-69
	A-77
	Requirements - Receiver Assembly Collector Subsystem Requirement - Tower Assembly Energy Storage Subsystem



## Section 1 PHASE I PROGRAM INTRODUCTION

The Solar Thermal Power Systems Office of the Division of Solar Energy of DOE has initiated several application-oriented programs, one of which is the Small Power Systems Program. The overall objective of this program is to develop and foster the commercialization of modular solar thermal power systems for application in the 1 to 10 MWe range. Potential applications include power systems for remote utility applications, small communities, rural areas, and industrial users. Engineering Experiment No. 1 represents the first small power system to be developed under this program.

The primary goal of Engineering Experiment No. 1 (EE1) is to identify suitable technological approaches for small power systems applications and to design, fabricate, field install, test and evaluate a solar power facility based on an optimum use of near-term technologies. Investigation of the performance, functional, operational and institutional interface aspects of such a facility in a field test environment are additional objectives.

Engineering Experiment No. 1 will be conducted in three phases: Phase I - Concept Definition, Phase II - Design and Development Testing, and Phase III - Plant Construction and Testing. Three candidate programs for EE No. 1 are shown in Figure 1-1.

Phase I objectives were to investigate various system concepts and develop information which will allow selection of the most appropriate system for the first small power system application. System design and system optimization studies were conducted considering plant size, annual capacity factor, and startup time (the time from start of Phase I to the initiation of testing in Phase III) as variables. The primary output of Phase I was to be the definition of preferred system concepts for each startup time, design sensitivity and cost data for the systems studied, and Phase II Program Plans for each preferred system concept.



#### THREE CANDIDATE PROGRAMS FOR EE NO. 1

PROGRAM	YEARS FROM PHASE I START										
STARTUP		1	2	3	4	5 (	5	7		•	10
TIME	CY78	79	20	81	82	#3	84	35	96	87	-
				ON	-LINE						
3.5 YEAR	P.		ή [	P-111	TEST	i i				l	1
YEAR		40) (8 M		22 MO)	(12 MO)						1
	-		1	1		LINE				<del> </del>	†
4.5	[P4	<del></del>	Pill	7	-in -	TEST	i	1 1		1	1
YEAR	(10 )		18 MO)	_	24 MO)	(12 MO)		1 1			
							OF	LINE			1
6.5 YEAR	P.			P-11		p.	111	TEST		1	1
YEAR	(10 A	(O)		42 MO)		(24	MO)	(12 MO)			1
OMMERCIAL			1								$\Box$
DBJECTIVE			}						<del></del>	1	T
				<u>L</u>	1	1				1	1

- THREE PROJECT PHASES
  - I CONCEPT DEFINITION
  - II PRELIMINARY AND DETAILED DESIGN;
    COMPONENT/SUBSYSTEM DEVELOPMENT/TESTING
  - 111 FABRICATION, INSTALLATION, TEST AND EVALUATION
- CATEGORY A CANDIDATE SYSTEMS GENERAL, EXCLUDING DISH CONCENTRATORS

Figure 1-1. Overall Program Scope

Phase II involves the preliminary and detailed design of the preferred system, and component and/or subsystem development testing that are needed before proceeding with plant construction in Phase III. Phase II may be from 8 to 42 months depending on the program selected by JPL as a result of Phase I.

Phase III will consist of subsystem fabrication, plant construction, installation, testing, and evaluation of the solar power facility (Engineering Experiment No. 1). A 3-year schedule is anticipated for this phase, with testing conducted during the third year.

Late in the Phase I study period, DOE concluded that a better balance of the overall solar thermal electric program could be achieved by limiting the JPL Small Power Applications activities to point-focus distributed systems. Consequently, DOE directed that JPL take the necessary steps to constrain the JPL-managed First Engineering Experiment (EE No. 1) to point-focusing distributed receiver technology for all phases beyond Phase I. Accordingly, on 3 April 1979, all MDAC efforts on Phase II program planning were terminated by JPL directive.

### 1.1 STUDY TASK APPROACH

į

Phase I study objectives were: (1) select preferred system concepts for each of the three program durations, (2) complete conceptual designs for each of three system concepts, (3) provide sensitivity data over a range of; plant rating: 0.5-10 MWe; annual capacity factor: 0 storage to 0.7, (4) prepare detailed Phase II plans and cost proposal (3 versions of EE No. 1), (5) prepare Phase III program and cost estimates (3 versions of EE No. 1), and (6) recommend preferred EE No. 1 program. Three major tasks were planned for the 10-month Phase I effort. They were Task 1 - Development of Preferred System Concepts, Task 2 - Sensitivity Analyses, and Task 3 - Phase II Program Plans. The Top-Level study flow is indicated in Figure 1-2.

In Task I, three preferred concepts were defined to the conceptual design level. The concepts were consistent with the three specified program startup times of 3.5, 4.5, and 6.5 years. In Task I, power plants were considered

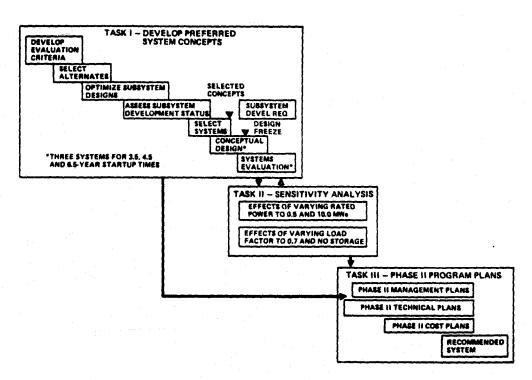


Figure 1-2. Top-Level Study Flow

for a nominal 1.0 MWe rated capacity and 0.4 capacity factor. Activities in Task I through the selection of the three preferred system concepts were primarily a systems engineering/evaluation conducted by MDAC. Subsystem characteristics, performance, and preliminary development requirements were supplied by the appropriate subcontractors. Following this concept selection, the conceptual design of subsystems was initiated in which descriptions, finalized development requirements, performance, reliability, and cost data for each of the three selected concepts were developed.

In Task II, the impact of varying rated power (0.5 and 10.0 MWe) and system capacity factor (zero storage case and 0.7) was investigated. Sensitivity analysis in Task II was performed by MDAC using subsystem data supplied by the subcontractors. This task featured system and subsystem reoptimization for each of the cases evaluated.

In Task III, the management, technical and cost plans for Phase II for each of the three selected concepts were to be prepared in accordance with JPL guidelines and MDAC system recommendations were to be provided. However, as reviewed above, during the latter period of the contract, JPL directed MDAC to terminate all Task III efforts. Accordingly, Task III efforts were disecontinued and Phase II Program Plans are not reported.

### 1.2 ROLES AND RESPONSIBILITIES

A team of companies led by the McDonnell Douglas Astronautics Company (MDAC) was contracted to conduct the Phase I definition of Category A systems (general only, excluding dish concentrators). The team includes MDAC, Rocketdyne, Stearns-Roger, the University of Houston Energy Laboratory, and Energy Technology, Incorporated (ETI). MDAC was the prime contractor for the effort and was responsible for overall contract compliance. The four major subcontractors and their prime areas of responsibility were: (1) Rocketdyne Division of Rockwell International (receiver, dual-media energy storage), (2) Energy Technology, Inc. (radial turbine and gearbox), (3) Stearns-Roger (tower and plant layout/equipment), and (4) University of Houston Solar Energy Laboratory (collector field optimization).

### 1.3 SYSTEM SUMMARY

From the preliminary design analyses efforts to date, MDAC concludes that the proposed central receiver power system concept is a feasible, low-cost, and low-risk approach for a small solar power system experiment. It is particularly suitable for early deployment under the 3.5- and 4.5-year programs. The concentrator subsystem is currently under development and low-cost, highproduction rate heliostats will be available for this program. The proposed receiver subsystem using Hitec is similar to existing fossil fired/Hitec heaters. The tower is a standard low-cost guyed steel tower. The energy transport system using Hitec is based on standard state-of-the art equipment and operating conditions. For the 3.5- and 4.5-year programs, a simple two-tank storage subsystem is proposed which requires no development. The power conversion system is based on existing axial steam turbines. All the balance of plant equipment involves state-of-the-art equipment and processes. The 6.5-year program contains development of a radial outflow turbine and qualification of a dual media thermocline storage subsystem. The technology employed in all programs is consistent with the development time available. Thus, the proposed MDAC concepts satisfy all of the important JPL selection criteria, namely, high operational reliability, minimum risk of failure, good commercialization potential, and low program costs.

### 1.4 EXPERIMENTAL SYSTEM DESCRIPTIONS

This volume contains the preliminary descriptions of the experimental systems proposed for each of the three specified startup programs (3.5, 4.5, and 6.5 year EE No. 1 programs). Section 2 presents a brief summary of the EE-1 concepts. Section 3 presents the overall design approach taken with emphasis on the interaction between the design approach and the groundrules and evaluation criteria established by JPL.

Section 4 contains EE-1 system and subsystem descriptions. Fabrication and installation characteristics are covered in Section 5, with maintenance and repair characteristics given in Section 6. Development requirements for each EE-1 subsystem are covered in Section 7. Appendix A contains preliminary requirement specifications for the total system and all subsystems. All supporting analyses and trades studies are included in Volume V. EE-1 cost data for Phases II and III are also summarized in Volume V.



### Section 2 SUMMARY

From the design and analyses efforts conducted under this program phase, MDAC concludes that the proposed small central receiver power system concept is a feasible, low-cost, and low-risk approach for the first small solar power system engineering experiment (EE No. 1). It is particularly suitable for early deployment using state-of-the-art technology under the 3.5- or 4.5-year programs.

The McDonnell Douglas small central receiver plant concept is illustrated in Figure 2-1. The complete system is made up of five major subsystems: the collector, power conversion, energy transport, energy storage, and the plant control subsystem, as shown in Figure 2-2.

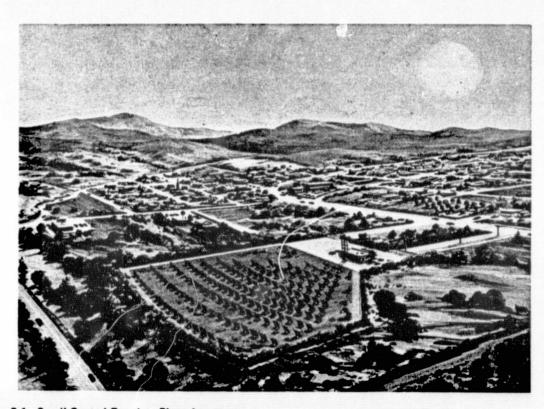


Figure 2-1. Small Central Receiver Plant Arrangement

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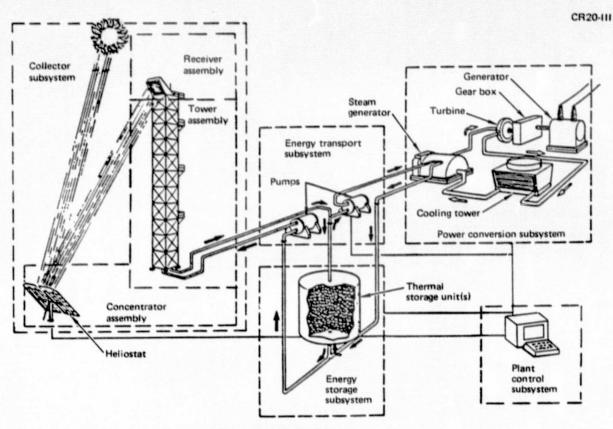


Figure 2-2. Concept for Small Electric Power System Module

The collector subsystem consists of concentrator, receiver, and tower assemblies. The concentrators comprise a field of two-axis tracking reflectors, called heliostats, which reflect and concentrate solar radiation onto a tower-mounted receiver. The heliostat field is located north of the receiver tower, as shown in Figure 2-3. Trim lines defining the field for the three versions of EE No. 1 are shown on the figure. The heliostats are based on the design developed by McDonnell Douglas for the DOE 10-MWe central receiver plant being built near Barstow, California. Thus, low-cost, high-production rate heliostats will be available for this program. Each heliostat is mounted on a pedestal with azimuth and elevation drives and has a total of 49 square meters of reflecting area (45.2 square meters for the 3.5-year program). The heliostat field utilizes an open-loop control system to track the sun. A standard, lowcost steel tower, 40 meters high, stabilized by guy wires, supports the receiver. The receiver is configured as a partial cavity to enhance thermal performance. Standard coiled pipe using existing fabrication techniques is employed for the absorber panel to maximize reliability and minimize program risks.

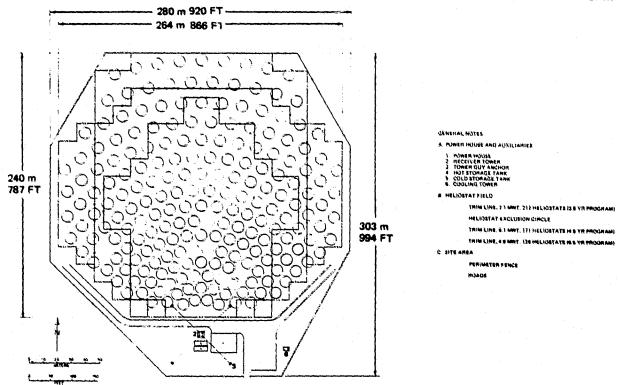


Figure 2-3. Representative Field Layout

The energy transport subsystem uses a mixture of salts with a low melting temperature to transport thermal energy from the receiver to the energy storage subsystem and thence to the power conversion subsystem. Hitec, consisting of 53 percent KNO3, 40 percent NaNO2, and 7 percent NaNO3, is used for the 3.5-year and 4.5-year programs, because of its low melting temperature (142°C) and common use in industrial processes. The binary mixture of 54 percent KNO3 and 47 percent NaNO3, denoted as HTS, is used for the 6.5-year program, because it has a higher temperature capability (increasing system performance) and is more economical. The energy transport system is based on standard state-of-the-art equipment and operating conditions.

The energy storage subsystem both isolates the power conversion subsystem from the collector subsystem and stores thermal energy for extended operation. For the 3.5- and 4.5-year programs, a simple two-tank storage subsystem is utilized which requires no development. For the 6.5-year and commercial programs, the storage unit consists of a single tank with 75 percent of its volume filled with crushed taconite (iron ore). The salt/taconite mixture

stores the thermal energy as sensible heat with the salt also functioning as the heat transfer medium. The tank is sized to operate the solar plant at the rated power of 1 MWe with a 0.4 annual capacity factor.

Steam produced from the steam generator drives a steam Rankine cycle turbine which in turn drives an electrical generator to produce electricity. For the 3.5- and 4.5-year programs, an existing axial steam engine is utilized. For the 6.5-year and commercial programs, a radial outflow turbine currently under development by Energy Technology, Inc. (ETI) is utilized. Waste heat from the turbine is rejected by a wet cooling tower.

All the balance of plant equipment involves state-of-the-art equipment and processes. The technology employed for each EE No. 1 program concept is consistent with the development time available. Thus, the proposed MDAC concepts satisfy all of the important JPL selection criteria, namely, high operational reliability, minimum risk of failure, good commercialization potential, and low program costs.

Subsystem characteristics and basic design differences for each EE No. 1 system concept and the ultimate commercial system are summarized in Figure 2-4. A summary of system performance data for the 4.5-year program design is given on Table 2-1. More detailed information on each concept is contained in Section 4 of this volume.



	3.5-YEAR PROGRAM	4.5-YEAR PROGRAM	6.5-YEAR PROGRAM	COMMERCIAL PROGRAM
MEDIA MAX MEDIA TEMP <sup>O</sup> C ( <sup>O</sup> F) TURBINE INLET PRESS., BARS (PSIA)	HITEC 454 (850) 62 (900)	HITEC 510 (950) 103 (1,500)	HTS 538 (1,000) 121 (1,750)	HTS 566 (1,050) 138 (2,000)
SUBSYSTEMS  • COLLECTOR  - CONCENTRATOR ASSEMBLY	10 MWe BARSTOW PLANT	SECOND GENERATION	SECOND GENERATION	SECOND GENERATION
- RECEIVER ASSEMBLY	316SS	316SS	INCONEL-800 (ALT-316SS)	INCONEL-800 (ALT-316SS)
- TOWER ASSEMBLY	STANDARD EQUIPMENT	STANDARD EQUIPMENT	STANDARD EQUIPMENT	STANDARD EQUIPMENT
• ENERGY STORAGE	TWO-TANK	TWO-TANK	DUAL-MEDIA	DUAL-MEDIA
• ENERGY TRANSPORT (COLD/HOT LINES)	CARBON-STEEL/ 31655*	CARBON-STEEL/ 316SS	CARBON-STEEL/ 316SS	CARBON-STEEL 316SS
• FOWER CONVERSION	AXIAL TURBINE	AXIAL TURBINE	ROF TURBINE	ROF TURBINE
• PLANT CONTROL	MANUAL	MANUAL	SEMI-AUTOM	FULLY AUTOMATIC

\*SELECTED FOR EXPERIMENT SYSTEM FLEXIBILITY — ALL CARBON STEEL ADEQUATE

Figure 2-4. Subsystem Characteristics

Table 2-1. System Performance Data (4.5 Year EE-1 Program)

```
SYSTEM DATA
     Rating
                                1 MWe (Net)
     Capacity factor
                                0.4
     Availability
                                0.95
                                 30 years
     Operating life
     Land used
                                10 acres
                                16.3% at 1 MWe and no storage
     Efficiency
     Type
                                171 north field heliostats with tower mounted
                                central receiver
COLLECTOR SUBSYSTEM
                                60%
     Collector efficiency
     Concentrator module
                                49 m<sup>2</sup>/heliostat, 8380 m<sup>2</sup> total area
         Reflecting area
                                3.5 mrad total slope and pointing error
         Error
         Control
                                Open loop
     Receiver module
         Aperture
                                4.28 m dia. aperture
                                Partial cavity-cone
         Type
         Height
                                42 meters to centerline of receiver
                                6.05 MWt at 510°C (950°F)
         Output
                                288°C (550°F)
         Input
POWER CONVERSION SUBSYSTEM
     Type
                                Rankine cycle axial, marine type steam turbine
                                1 MWe
     Net output
     Parasitic loss
                                0.11 MWe
                                482°C (900°F)
     Inlet temperature
     Cooling
                                Wet cooling tower
     Efficiency
                                31.0%
ENERGY TRANSPORT SUBSYSTEM
     Type
                                Steel piping with Hitec transport fluid
     Efficiency
ENERGY STORAGE SUBSYSTEM
                                Hot tank/cold tank, Hitec, sensible heat
     Type
                                14.9 MWt-hr (4 hours)
     Storage
     Maximum temperature
                                 510°C (950°F)
     Minimum temperature
                                288°C (550°F)
                                96.5%
     Efficiency
```

## Section 3 DESIGN APPROACH

The general groundrules and approach taken for the conceptual design and analyses of the preferred system candidates are summarized in this section. Specific design definitions are contained in Section 4.

### 3.1 GENERAL GROUNDRULES

Several general groundrules for concept design and analyses have been specified by JPL for EE No. 1. Major groundrules, together with brief descriptions, are listed below.

- A. <u>Category A.</u> Of the three categories of solar concepts for EE No. 1 (Categories A, B, and C), MDAC was selected to investigate Category A which included (but was not limited to) central receiver and linear focusing systems. As described in Volume II, the central receiver was clearly superior to alternative Category A candidates. Although many of these superior features also apply relative to dish concentrators (Categories B and C), they will not be developed here since they are outside the scope of the MDAC contract. Originally, these comparisons would have been made prior to selecting the Phase II concept using the Phase I study results from all three contractors. However, as discussed in Section 1, the central receiver will not be considered for EE No. 1.
- B. <u>Technology Status</u>. As specified by JPL, the prime goal of the first small power system engineering experiment (EE No. 1) was to identify suitable technological approaches for small power systems applications and to design, fabricate, field install, test and evaluate a solar power facility based on the optimum use of near-term technologies. Based on this groundrule, MDAC proposed designs that were primarily based on existing or near-term hardware and technologies and/or equipment currently being developed on other programs.
- C. <u>Development Milestones</u>. JPL established three specific development program durations to be investigated during Phase I. These programs are referred to as the 3.5-year, 4.5-year, and 6.5-year programs, which represent the time interval from the start of the Phase I contract to the "on-line" point



at which the EE-1 plant has been constructed and is ready to deliver rated power. These time intervals were considered as major program milestones which were not to be exceeded. Other program schedule milestones were defined by JPL, such as the time interval for each program phase and the gaps between each phase. These phasing milestones are reviewed in more detail in Volume II, Sections 3.1.2, 3.4, and 3.5 and Volume III, Sections 1 and 7.

The most important milestone was the duration of Phase II, during which EE No. 1 preliminary and detailed designs were to be completed, and critical subsystems or components tested. The Phase II durations specified by JPL were 8, 18, and 42 months for the 3.5-, 4.5-, and 6.5-year programs, respectively. The 8-month Phase II duration for the 3.5-year program was so short that virtually no development testing was possible. Consequently, all subsystems and components for this program had to be based on existing equipment and technology with minimum modifications. Operating conditions were selected to permit this approach. For the 4.5-year program, the 18-month Phase II duration permitted operating conditions (temperatures and pressures) to be increased and subsystems/components to be improved. Development testing on the receiver assembly was proposed for this program. For the 6.5-year program, the 42-month Phase II duration permitted development and qualification of subsystems with performance closely approximating the ultimate commercial small power system. The selection of specific systems and components as affected by these development requirements is covered in Volume II, Sections 3.1, 3.4 and 3.5. The determination of specific subsystems or components for development testing of each of the EE-1 concepts during Phase II is covered in Section 7 of this volume.

D. <u>Selection Criteria</u>. In order to make meaningful comparisons between the different system concepts proposed by the Category A, B, and C contractors, and to aid each contractor in specific system design, JPL identified several system selection or evaluation criteria that were to be used in their assessment of each concept. These system concept selection criteria, in descending order of importance, are summarized in Figure 3-1. MDAC explicitly applied these evaluation criteria to define system configurations for each program startup time, and also imposed these criteria as requirements for subsystem component design for each version of EE No. 1. The approach to the flowdown from these evaluation criteria to subsystem requirements is described below. The application of these evaluation criteria to system and subsystem design is covered throughout this documentation.

A direct comparison of the three system categories according to the selection criteria would have provided valuable insight and guidance for the Small Power Systems program.

### 3.2 GENERAL APPROACH

In order to ensure the best design choices for each version of EE No. 1, the system selection criteria from Figure 3-1 were expanded into specific requirements for system and subsystem definition. These requirements were then either incorporated into system and subsystem specifications (contained in Appendix A of this volume) or used as high-level evaluation criteria for trade studies at all levels of system definition. This flowdown from the evaluation criteria to specific requirements is described in the following paragraphs.

- 1) HIGH OPERATIONAL RELIABILITY SELECTED SYSTEM CONCEPTS SHOULD LEAD TO:
  - A COMMERCIAL PLANT THAT OPERATES WITH A HIGH RELIABILITY DURING ITS LIFETIME (TYPICALLY 30 YEARS)
  - AN EXPERIMENTAL PLANT WHICH WILL START UP SATISFACTORILY AND OPERATE RELIABLY FOR AT LEAST TWO YEARS AFTER STARTUP WITH MINIMUM FORCED OUTAGES ATTRIBUTABLE TO DESIGN DEFICIENCIES AND HARDWARE FAILURES

(ENHANCEMENT OF RELIABILITY THROUGH MODULARITY/REDUNDANCY SHOULD BE CONSIDERED)

- 2) MINIMUM RISK OF FAILURE SELECTED CONCEPTS SHOULD MINIMIZE DEVELOPMENT RISK AND THEREBY PROVIDE HIGH CONFIDENCE THAT SUBSYSTEM DEVELOPMENT CAN BE ACHIEVED WITHIN PHASE II TIMES AND THAT THE EXPERIMENT CAN BE BROUGHT ON-LINE AT THE SPECIFIED STARTUP TIMES
- 3) COMMERCIALIZATION POTENTIAL SELECTED CONCEPTS SHOULD USE OR CONTRIBUTE DIRECTLY TO THE EVENTUAL SYSTEMS THAT ARE LIKELY TO ACHIEVE COMMERCIAL SUCCESS IN THE LATE 1980'S
  - COSTS/PERFORMANCE
  - FLEXIBILITY (MODULARITY SHOULD BE ONE OF PRIMARY CONSIDERATIONS)
  - INSTITUTIONAL INTERFACE ASPECTS
- 4) LOW PROGRAM COSTS -- CONCEPTS SHOULD BE SELECTED TO MINIMIZE THE ESTIMATED DEVELOPMENT AND CAPITAL COSTS OF PHASE II AND PHASE III

Figure 3-1. Selection Criteria (in Order of Importance)

## 3.2.1 Flowdown from Reliability/Availability Criterion

Constraints and guidelines imposed on subsystem design in order to meet the reliability/availability criterion are as follows:

- Use fully qualified hardware.
- Select the most reliable components.
- Prefer equipment with extensive operating experience.
- Employ conservative design practices.



- Seek design simplicity.
- Utilize redundancy where effective.

The great emphasis placed on this criterion for both the experimental plant and the resulting commercial unit demands a rigorous adherence to the conditions listed. The first three conditions are paramount in selecting plant equipment. The first condition precludes selection of any components not able to be fully qualified for all operating, lifetime, and environmental requirements. An example of the application of this condition will be to constrain concentrator selection to candidates having substantial prior development and qualification. The second condition can have a major impact on system reliability/availability due to substantial differences in component failure rates. An example of applying this condition would be the selection of a marine-type turbine over a standard industrial design. Extensive prior operating experience is preferred so that historical failure rate data is available to make reliability/availability predictions with confidence and to avoid any surprises.

The last three conditions relate to design practices to be employed at both the system and subsystem level. Conservative design allows margins for any unforeseen conditions and produces a "forgiving" system. Simplicity is always important to achieving system reliability through minimizing both potential sources of failure and "surprises." Redundancy of key elements should be used to reduce single point failure but only where it is effective. Redundancy inherently complicates the system, conflicting with the simplicity condition above, and imposes additional sources of failure. An example of ineffective redundancy was the full replication of the power conversion equipment analyzed in Volume II, Appendix C.

Strict application of these conditions to EE No. 1 design will produce "an experimental plant which will start up satisfactorily and operate reliably for at least two years after startup with minimum forced outages attributable to design deficiencies and hardware failures." Violation of these conditions ensure the opposite.

## 3.2.2 Flowdown from Program Risk Criterion

Minimizing the risk of failure (either technical or schedule) imposes the following conditions on EE No. 1 design:



- Minimize development within the EE No. 1 program.
- Utilize standard fabrication techniques and processes.
- Select materials and equipment that are available without excessively long lead times.
- Provide schedule pads for all activities--particularly development and tests (this limits development objectives).
- Select equipment with viable backups available where there is any chance of failure.

These conditions are all self-explanatory but are necessary in order to "provide high confidence that subsystem development can be achieved within Phase II times and that the experiment can be brought on-line at the specified startur times."

### 3.2.3 Flowdown from Commercialization Criterion

Although the commercialization criterion strictly applies to the commercial design (described in Volume IV), conditions will be imposed on the design of EE No. 1 so that they can logically evolve into a commercially viable system. Three categories of conditions will be developed based on the three sub-elements of the commercialization criterion.

### 3.2.3.1 Costs/Performance

Achievement of commercially competitive energy costs imposes the following conditions on the commercial design:

- Low capital costs.
- Low maintenance costs.
- Minimum site assembly.
- Unattended operation.
- High efficiency.

These conditions will be approximated in the EE No. 1 design as closely as is consistent with the higher-level criteria described earlier.

### 3.2.3.2 Flexibility

This criterion requires that the commercial version be capable of meeting the power needs of different users at different sites with different power demands and duty cycles. This is an extremely important criterion for producing a useful power plant capable of the extensive deployment required to achieve the



economies of production scales without excessive "customizing" costs for each installation. Although they are required only for the commercial version, conditions derived from this criterion must be imposed on the designs generated for EE No. 1 in order to provide a useful experimental plant leading to a commercially viable system. These conditions are:

- Finite number of modules to cover power range of 1 to 10 MWe.
- Thermal storage, excluding battery storage.
- Road-transportable modules.

The flexibility to meet differing power level requirements in the 1 to 10 MWe range requires that equipment be designed to cover this range with no more than five (preferably four) discrete modules. The figures are consistent with common industrial practice, as exemplified by commercial turbines, which are produced to standard frame sizes but which can be applied over a range of power levels up to some maximum.

Power demand profiles are not expected to exactly match solar availability. As a consequence, storage must be provided to make the collected energy available when it can be used by the customer. This imposes more storage than the minimum required to meet the annual capacity factor. Although, as an experimental plant, EE No. 1 will be configured with this minimum storage, the storage concept must be selected to provide greater flexibility in the commercial versions—both to meet differing duty cycles and to provide higher annual capacity factors. As shown in Volume II, battery storage is far too costly even if the DOE development and cost goals for advanced batteries are achieved. As a result, thermal storage must be employed to meet this criterion.

Widespread deployment of small power systems require that the system be configured from road-transportable modules. This is particularly important for the concentrator, since it is the component which is necessarily large in area. Reasonable costs demand factory preassembly of the majority of the concentrator into road-transportable elements requiring minimum site-assembly operations. This contrasts with large power systems which could amortize site assembly (startup and shutdown) operations over a higher power rating.

### 3.2.3.3 Institutional Interface

The two major conditions imposed on subsystem design to meet this criterion are:

- Minimize all hazards.
- Employ standard technology to the greatest extent possible.

### 3.2.4 Low Program Costs

The conditions imposed to meet this criterion are divided into categories according to the two program phases.

### 3.2.4.1 Low Costs in Phase II

Conditions imposed to achieve low program costs in Phase II are:

- Minimum development (redundant with condition from program risk criterion).
- Utilize other DOE development programs to the greatest extent possible.

### 3.2.4.2 Low Costs in Phase III

Conditions imposed to limit Phase III costs are:

- Use commercially available equipment wherever possible.
- Use solar equipment being produced for other programs if possible.
- Maximize system efficiency (redundant with condition from commercialization criterion).
- Maximum system simplicity (redundant with conditions from reliability criterion).

As reviewed above, the general groundrules and selection criteria imposed by JPL will have a significant impact on the overall MDAC design approach. Its specific detailed application will be seen in the balance of this document.

In order to facilitate the development of EE No. 1, preliminary system and subsystem specifications were also developed as a part of this Phase I effort. These specifications are included as Appendix A to this volume. A cross-reference index that relates the specification requirements to system/ subsystem design sections of Volume III (EE-1 System) and Volume IV (Commercial System) is given in Table 3-1.



Table 3-1. Specification/Design Cross Index

		Des	Design		
	Specification	EE-1	Commercial		
Topic	Volume III Appendix No.	Volume III Section No.	Volume IV Section No		
• Overall System	A.3.1	4.1	3.1		
<ul> <li>Collector Subsystem - Concentrator Assembly</li> </ul>	A.3.2	4.2	3.1.1		
<ul> <li>Collector Subsystem - Receiver Assembly</li> </ul>	A.3.3	4.3	3.1.1		
<ul> <li>Collector Subsystem - Tower Assembly</li> </ul>	A.3.4	4.4	3.1.1		
• Energy Storage Subsystem	A.3.5	4.5	3.1.2		
• Energy Transport Subsystem	A.3.6	4.6	3.1.3		
Power Conversion Subsystem	A.3.7	4.7	3.1.4		
Plant Control Subsystem	A.3.8	4.8	3.1.5		
Supporting Sections for All System	s/Subsystems	Volume III	Volume IV		
• Operations		4.1-4.8	3.2		
<ul> <li>Fabrication and Installation Cha</li> </ul>	racteristics	5.0	3.3		
- Procurement, Manufacturing, an	d Assembly	5.1	3.3		
- Transportation and Handling		5.2	4.3		
- Plant Construction and Equipme	nt Installation	5.3	4.4		
- Checkout and Adjustment		5.4	4.4		
- Safety Aspects (Installation)		5.5	3.5		
<ul> <li>Maintenance and Repair Character</li> </ul>	istics	6.0	3.4		
- Reliability/Availability		6.1	3.4		
- Inspection and Maintenance		6.2	3.4		
- Maintenance Equipment and Faci	lities	6.3	4.3		
- Safety Aspects (Maintenance)		6.4	3.5		

# Section 4 EXPERIMENTAL SYSTEM DESCRIPTION

Conceptual design descriptions of the preferred systems for the three specified EE-1 programs startup times are contained in this section. Each system is based on a nominal 1.0-MWe power rating and a 0.4 capacity factor. Conceptual design information includes an overall system description (Section 4.1) and major subsystem descriptions (Sections 4.2-4.8). Descriptions include design, performance, and operational characteristics. Additional information related to fabrication and installation, maintenance and repair, and safety are contained in Sections 5.0 and 6.0. System analyses and trade studies in support of these descriptions are in Volume V and preliminary information on the sensitivity to variations in power rating and capacity factor are in Volume IV.

### 4.1 OVERALL SYSTEM DESCRIPTION

Design, performance, and operational characteristics of the three versions of EE No. 1 are contained in this section.

## 4.1.1 Design and Performance Characteristics

Overall system designs for the alternate experimental plant are described here. As described in Section 3, these designs were arrived at by attempting to approach the selected commercial system to the extent possible consistent with the three programs times allowed. The top level characteristics for all designs are:

System Electrical Output 1 MW (Net)

System Capacity Factor 0.4
System Availability >0.95

Insolation Model Barstow 1976

A summary of system characteristics for three alternative EE-1 designs is given in Table 4.1-1.



Table 4.1-1. System Characteristics Summary

	3.5-Year	4.5-Year	6.5-Year
Receiver Outlet/ Steam Gen. Inlet Temperature °C, (°F)	<b>4</b> 54 <b>(</b> 850)	510 (950)	538 (1000)
Receiver Inlet/Steam Gen. Outlet Temperature, °C, (°F)	260 (500)	288 (550)	288 (550)
Peak Receiver Power, MWt	7.08	6.05	4.87
Receiver Flowrate Kg/hr (lb/hr)	84,000 (185,100)	62,800 (138,400)	44,900 (99,000)
Fluid	Hitec	Hitec	HTS
Receiver Aperture Dia. m, (ft)	4.50 (14.8)	4.28 (14.1)	4.00 (13.1)
Tower Ht. m, (ft)	39 (128)	39 (128)	39 (128)
Heliostats, No.	217	171	139
Heliostat Area, $m^2(ft^2)$	45.2 (486)	49.0 (528)	49.0 (528)
Thermal Storage Capability (MWt)	16.9	14.3	11.3
Storage Technique	Two-Tank	Two-Tank	Dual-Media Thermocline
Turbine Type	Axial	Axial	Radial
Turbine Inlet Temperature C ( F)	427 (800)	482 (900)	<b>51</b> 0 (950)
Turbine Inlet Pressure, Bars (Psia)	62 (900)	103 (1500)	121 (1750)
Turbine Expansion Efficiency	0.70	0.75	0.84
Power Conversion Efficiency (Thermal to Gross Electrical)	0.268	0.310	0.380

The alternate designs for Engineering Experiment No. 1 are generically similar to the proposed commercial system. All designs are of the central receiver type, utilizing a molten heat transfer salt (HTS) as both the receiver coolant and the thermal storage fluid. The design of the 3.5-year version will be given as a reference and variations for the other programs noted as required.

The system is designed so that operation of the power conversion subsystem (PCS) is decoupled from the operation of the receiver/concentrator subsystems. This is accomplished by the use of two separate energy transport loops; one extracting energy from the receiver and depositing it in the storage subsystem, the other extracting energy from the storage subsystem and supplying it to the PCS.

The system can be divided into five principal subsystems as is shown in Figure 2.1-2. Schematics for the alternative designs are shown in Figures 4.1-1 through 4.1-3. The concentrator assembly includes the required heliostats, cables and controls. The receiver assembly consists of the absorber, insulation, enclosure, and instrumentation. The receiver is supported by the tower assembly which also provides receiver maintenance facilities and supports the piping to and from the receiver. The energy transport subsystem includes all of the Hitec/HTS piping and flow control equipment. The energy storage subsystem includes the thermal storage tank(s) and instrumentation. The power conversion subsystem includes all water/steam loop components from the steam generator to the heat rejection equipment. Also included in this subsystem are the generator, electrical switch gear, emergency power unit and water treatment equipment. The plant control subsystem provides control for all plant operations.

## 4.1.1.1 Collector Subsystem - Concentrator Assembly

The function of the concentrator assembly is to collect, redirect, and focus solar insolation on a receiver aperture that is centrally mounted on a tower. The concentrator assembly consists of a north field of heliostats plus related controls and necessary electrical power supply for drive purposes. The heliostats are individually mounted on pedestals and are segmented for easy

296 btu/lb

Figure 4.1-1. System Schematic (3.5-Year Program)

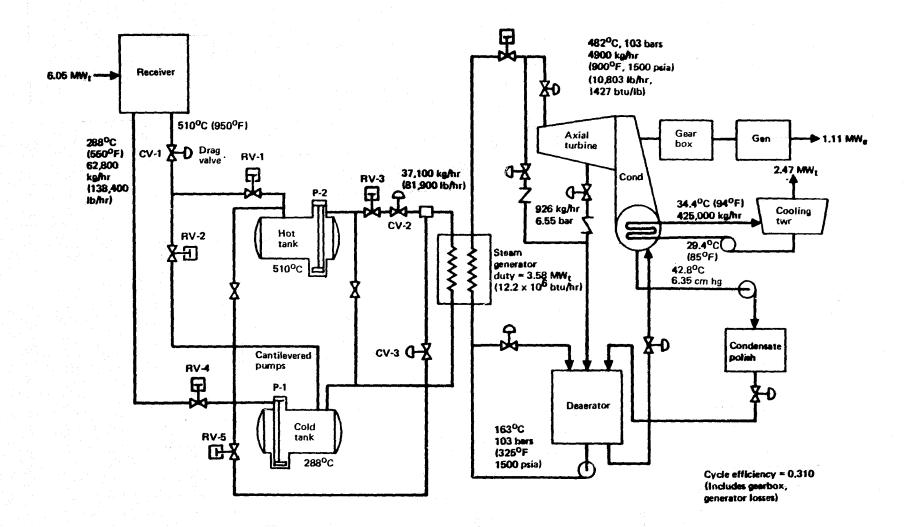


Figure 4.1-2. System Schematic (4 1/2-Year Program)

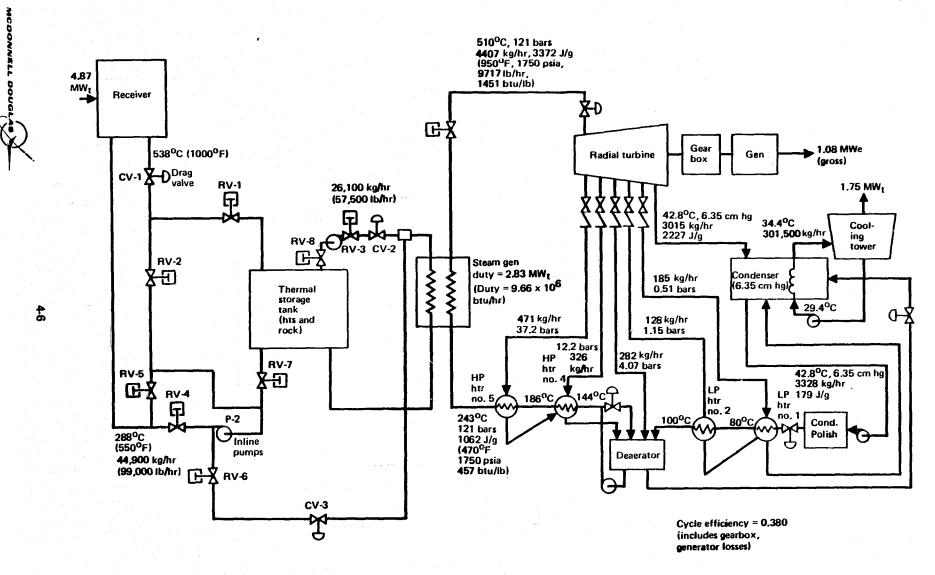


Figure 4.1-3. System Schematic (6-1/2-Year Program)

site assembly. Each heliostat has four subassemblies: the reflector panels, the drive unit, the pedestal support and foundation, and the control subassembly.

There are two reflector panels per heliostat and each panel is made up of six mirror modules. The mirror modules are second-surface glass mirrors. The modules are attached to a support structure that maintains their alignment and rigidly attaches them to the drive unit. Focusing is achieved by slightly curving the mirror modules during manufacturing, and by shimming the modules to the proper cant angles after attachment to the support structure.

The drive unit incorporates an azimuth and elevation drive mechanism. It is mounted on top of the pedestal and consists of motors, drive transmissions, position feedback sensors, reflector support bearings, and a structural housing. The drive unit positions the reflector during normal operation to redirect the solar beam radiation to the receiver aperture. The drive unit can also position the heliostat in an inverted stowage position to minimize the risk of damage from severe weather conditions.

The pedestal support and foundation is used to mount the heliostat in the field. A central support steel pedestal concept is used. The drive unit and reflector panels are mounted on top of the pedestal. The pedestal is rigidly attached to a precast concrete foundation by bolted flanges or slip joint.

Heliostat control is achieved from the control subassembly. Field controllers calculate the sun's position, direct individual heliostat motions, calculate any errors in position, and redirect corrective motions. Heliostat controllers calculate actual heliostat position, compare to the commanded position from the field controller, and drive the motors to correct the errors indicated. Power supply to the drive units and the control function are made through a "serial hook-up". This enables remaining heliostats to function normally should one heliostat fail. All heliostat controls have manual override capabilities.

The individual heliostat availability is 0.99987, and the probability that at least 98% of the field will be available is essentially unity. The heliostats meet all the design requirements specified by DOE. Performance requirements concerning survival in high winds, high temperatures, precipitation, and seismic disturbances have all been met or exceeded.

The collector subsystem for the 3.5-year program consists of a north field of 217 heliostats plus controls. Each heliostat has a reflective area of 45.2 m<sup>2</sup> and will be nearly identical to those used in the 10-MW Pilot Plant to be constructed at Barstow, California. The baseline concentrator field is illustrated in Figure 2-3. The heliostats are arranged to the north of the tower along a series of circular arcs centered on the tower. The heliostats in the outer arcs are staggered with respect to radial lines emanating from the tower to minimize blocking.

The small gaps in the field are necessary to preserve the radial-stagger configuration of heliostats and to maintain the proper azimutal spacing of heliostats. Filling of the spaces would place heliostats in the field which would not perform in a cost effective manner. Because of the optimized performance of radial stagger and proper azimutal spacing, the gaps in the field are necessary and do not degrade the figure of merit.

The collector system in the 4.5-year and 6.5-year programs employ the second generation heliostat with a reflector area of 49 m<sup>2</sup>. The 4.5-year program will require 171 heliostats with the 6.5-year program using 139 heliostats. The field size for these programs were indicated on Figure 2-3.

## 4.1.1.2 Collector Subsystem - Receiver Assembly

The receiver assembly consists of an absorber unit, structural assembly (including housing and doors), instrumentation, insulation, and heaters. The receiver faces south and the aperture is tilted downward 20 degrees off vertical. Receivers for the 3.5-, 4.5-, and 6.5-year programs will utilize Hitec/HTS fluid in a partial cavity arrangement. The absorber is a welded assembly of small diameter pipe, configured in a spiral pattern to absorb the energy from the heliostat field without exceeding fluid temperature



limits. Insulated doors close over the receiver face to prevent excessive cool down during periods of no insolation. Trace heaters keep the Hitec/HTS from cooling and solidifying.

## 4.1.1.3 Collector Subsystem - Tower Assembly

The primary function of the tower assembly is to provide support for the receiver. This support must support the receiver during the most severe wind and seismic conditions expected and also minimize receiver sway resulting in reflected solar energy missing the aperture. In addition, the tower provides support for the Hitec/HTS riser and downcomer and allows for necessary maintenance functions.

The tower assembly consists of the basic tower structure, supporting guy wires, foundations, working platforms, service elevator and ladders, lights, lightning protection, heliostat target device, electric power lines, water lines, and supports for heat transfer fluid lines, nitrogen purge lines, instrumentation and pneumatic lines. The tower is a guyed steel design complete with service elevator, caged ladder, and catwalk landings, at appropriate locations.

## 4.1.1.4 Energy Transport Subsystem

The energy transport subsystem includes all necessary Hitec/HTS circulation and flow control equipment. This subsystem is configured to allow independent operation of the receiver and power conversion subsystems, thus providing operational flexibility by permitting start-up, shut-down and normal operation of one subsystem while the other subsystem is in a different mode. This is accomplished by the use of two independent circulation circuits, each with its own circulation pump, control valves, isolation valves and sensors. The receiver loop extracts fluid from storage at a low temperature, pumps the cooled fluid to the receiver in a controlled manner to maintain a constant receiver outlet temperature and returns the heated fluid to the storage subsystem. A pump then sends the required quantity of "hot" Hitec/HTS through the second loop to the steam generator and returns the "cold" fluid to storage.

This subsystem is designed to allow easy daily start-up and shutdown and also provides for extended shutdowns. Trace heating equipment will be used to keep the Hitec/HTS in the molten stats during shutdowns and a nitrogen gas supply will be provided to prevent oxidation of the Hitec/HTS from occurring.

#### 4.1.1.5 Energy Storage Subsystem

The function of the energy storage system is to efficiently store the thermal energy absorbed by the Hitec/HTS at the receiver and provide it to the energy transport subsystem when required.

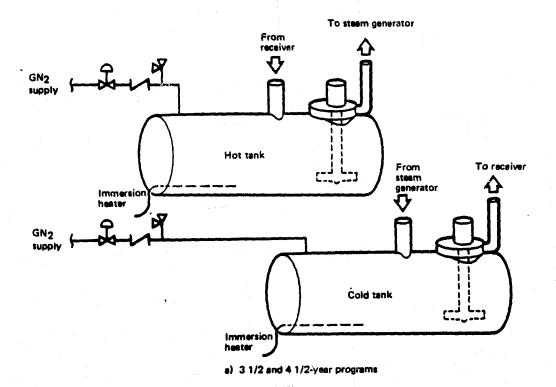
The 3.5-year energy storage subsystem consists of two insulated Hitec storage tanks, gaseous nitrogen supply, distribution manifolds, instrumentation and immersion heaters to facilitate start-up.

The 3.5-year energy storage subsystem operates in the following manner. Hitec is pumped from the "cold" tank at 260°C (500°F) and sent to the receiver and heated to 454°C (850°F) and then returned to the "hot" tank. Hitec is pumped from the "hot" tank and sent to the power conversion subsystem at the required rate to generate steam and then returned to the "cold" tank. This subsystem remains essentially unchanged for the 4.5-year programs with the exception of the higher Hitec operating temperatures (see Table 4.1-1). The two-tank concept is illustrated in Figure 4.1-4(A). The tanks will be below ground level in a pit to contain any accidental leakage of Hitec.

A single tank which uses a HTS + taconite mixture is employed for the 6.5-year program and illustrated in Figure 4.1-4(B). The storage is of the thermocline type where the thermocline moves up or down through the taconite mixture as hot HTS is added to or removed from the top manifold. The operating temperatures in the storage tank are also increased for the 6.5-year program, as shown in Table 4.1-1. Gaseous nitrogen is used in all programs to provide a blanket over the salt surface and prevent oxidation.

### 4.1.1.6 Power Conversion Subsystem

The function of the power conversion subsystem (PCS) is to convert the thermal energy stored in the Hitec/HTS into electricity and to then distribute this



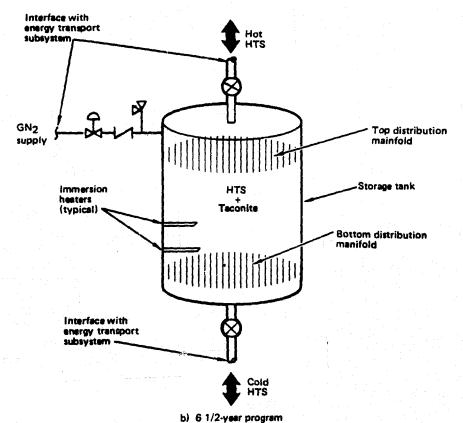


Figure 4.1-4. Energy Storage Subsystem Configurations

electrical energy to the electrical transmission grid and to the small auxiliary (parasitic) loads of the system.

The PCS generates power by use of a steam rankine cycle. The major components of the PCS are:

- Steam turbine-generator
- Steam generator
- Feedwater heaters, piping, pumps and valves
- Condenser and cooling tower
- Water treatment facilities
- Switchgear and plant electrical network

The selection of the steam turbine is one of the more critical elements in the design of the PCS. The 3.5-year program will utilize an existing conventional marine turbine capable of an expansion efficiency of approximately 0.70. The 4.5-year program will use an improved axial turbine to be developed as part of a DOE contract to develop a high-efficiency steam turbine. The radial outflow turbine, as developed by Energy Technology, Inc. (ETI), will be the prime mover in the 6.5-year program. This turbine offers significant performance advantages due to an expansion efficiency predicted to be 0.84 and the ability to provide up to five extraction ports for feedwater heating. Schematic diagrams of the PCS are shown in Figures 4.1-1 to 4.1-3 and give the pressures, temperatures, and flow rates required. The steam generator consists of a separate preheater, natural recirculation boiler and superheater section connected in series. Heat rejection, is accomplished with a wet cooling tower. Piping is carbon steel or admiralty alloy throughout. The water/steam loop will be blanketed with nitrogen at night to prevent oxidation and corrosion. All elements of the PCS have been selected for maximum reliability and are standard equipment requiring no major development effort with the exception of the turbine for the 6.5-year program.

## 4.1.1.7 Plant Control Subsystem

The Plant Control Subsystem provides the controls, monitors and interfaces for the operation of all the subsystems from a single central point. The Plant Control Subsystem provides for: (1) controlling all factors of each



subsystem, (2) monitoring all essential parameters of each subsystem, the protection and safety of the subsystem components, and (3) the integration of the subsystem controls into a coordinated plant operation.

The control and instrumentation functions are provided via: (1) the central control console, (2) redundant minicomputers and peripheral equipment, (3) the field and heliostat microprocessor based controllers of the concentrator subsystem, and (4) the Central Control unit and remote data acquisition and controller units of the plant.

The distribution of control and monitoring responsibilities of the plant control system are divided into the following functional categories:

- Supervisory and coordinated control central control directory for plant status monitoring and automatic controlling functions.
- Manual subsystem control central control directory for the manual control and monitoring of each subsystem.
- Element control control and monitoring directory of individually controlled elements of each subsystem.

## 4.1.1.8 Power Plant Building

The power plant building will contain the entire power conversion subsystem with the exception of the cooling tower and waste water pond. It will also contain the plant control subsystem and provide facilities for plant management, visitor control, and technical support. The building will be approximately 23 m  $\times$  17 m  $\times$  7 m (74 ft  $\times$  56 ft  $\times$  24 ft) with one main floor and one mezzanine floor. The substructures will be a truss-type structural steel frame pre-engineered and of pre-fabricated design and will be built to withstand all environmental loads of the specific site.

The external siding of the structure consists of prefabricated, painted panels of the proper thickness and configuration. An overhead monorail crane will be provided for maintenance of the turbine-generator. This structure will have evaporative cooling in the operating areas with localized air conditioning and heating units supplying the control and conference rooms.

Operating areas within the plant will be protected from fire by the use of local fire hose reels and fire extinguishers at critical points throughout the building. Automatic sprinkler systems will be provided in the operating area where deemed necessary. Computer and control rooms will be protected from fire by a suitable fire-suppression system. A general arrangement drawing for the baseline EE-1 plant building is provided in Figure 4.1-5.

#### 4.1.1.9 Performance

The performance of the system was analyzed by treating each of the subsystems separately and then combining the performances into an integrated system performance. The results of the performance analysis are presented graphically in the form of an energy "waterfall" chart in Figure 4.1-6. The sizing of the concentrator field was accomplished by starting at the net electrical energy required per year and working "backward", adding the various energy losses and inefficiencies until a figure representing the required total direct insolation per year is obtained.

The performance of the concentrator subsystem was analyzed by the University of Houston as part of the concentrator field optimization. This analysis was based on an annual insolation model that is nearly identical to measured Barstow insolation. The field performance parameters generated by the University of Houston were then input to the MDAC Program P5595, along with Barstow insolation, wind velocity, and ambient temperature data. The performance of the field was computed at 15 minute intervals for an entire year to obtain a more accurate estimate of the annual energy collection. The efficiency of the system for converting direct insolation to thermal energy is shown in Figure 4.1-7, as a function of time of day for several "good" days throughout the year. These efficiencies are essentially unchanged for the three experimental programs.

The performance analysis of the energy transport loop was based on steady state losses at normal operating temperatures and transient losses during periods of no insolation for typical duty cycles. Electrical trace heating energy requirements were also analyzed for the typical duty cycle. The

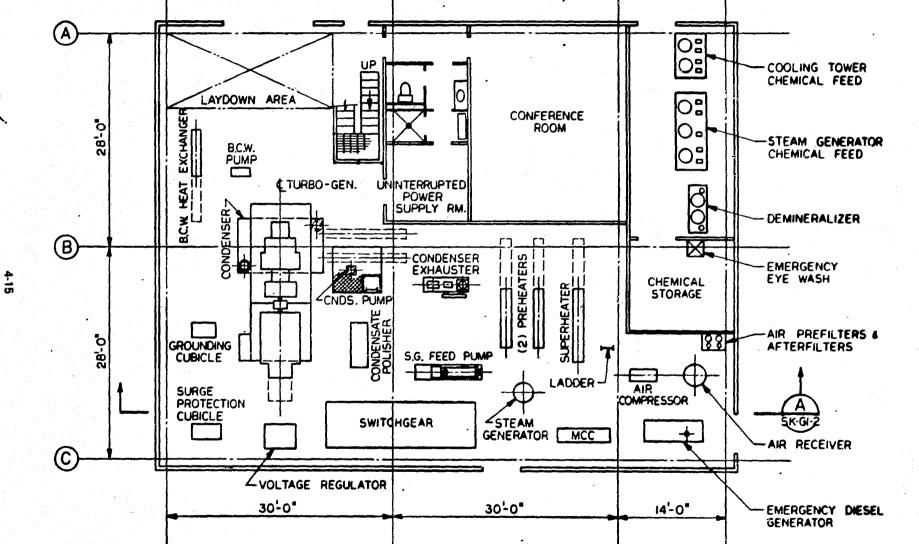


Figure 4.1-5. EE-1 Ground Floor Plan

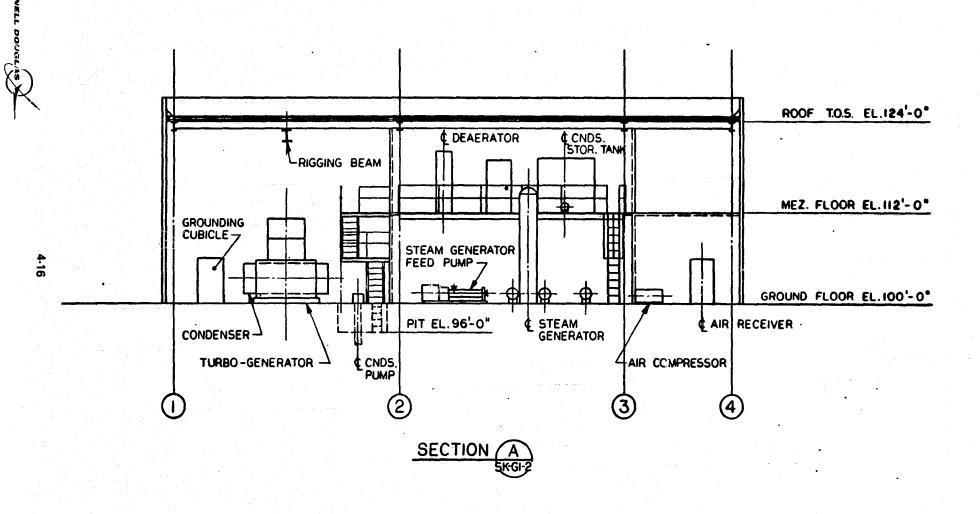


Figure 4.1-5. EE-1 Ground Floor Plan (Con't.)

Figure 4.1-5. EE-1 Ground Floor Plan (Con't.)

4



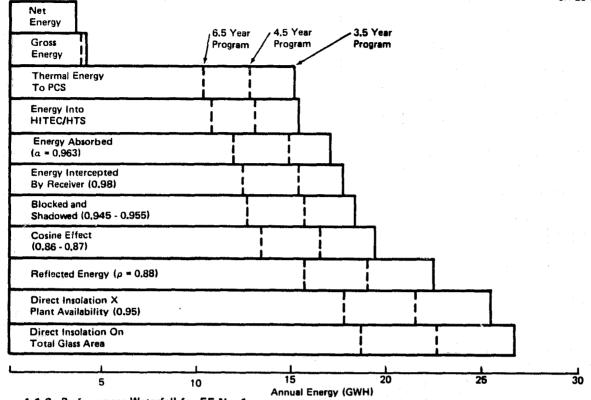


Figure 4.1-6. Performance Waterfall for EE No. 1

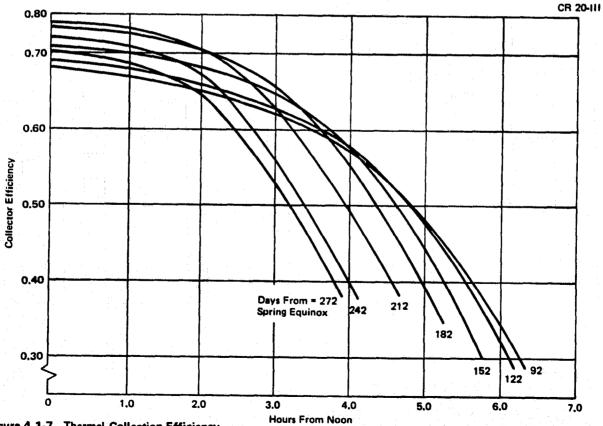


Figure 4.1-7. Thermal Collection Efficiency

thermal losses of the energy storage subsystem are also based on a typical duty cycle accounting for steady state thermal losses when storage is full and transient losses when storage is empty. Thermal losses of the power conversion system during normal operation, startup/cleanup, and nighttime cooldown were also computed based on a typical duty cycle. Parasitic power consumption of the auxiliary equipment was calculated based on the duty cycles used for each subsystem.

The gross electrical power capability of the turbine-generator, the emergency diesel generator requirements and the uninterruptable power supply requirements were then obtained from these results, in addition to the annual parasitic energy required.

The electrical energy produced by the system each month based on the Barstow insolation data is presented in Figure 4.1-8. This profile would be identical for all experimental programs.

## 4.1.2 Operational Characteristics

The operation of the plant has been divided into the following seven primary modes: Startup, Normal Operation, Intermittent Operation, Normal Shutdown, Emergency Shutdown, Standby, and Extended Shutdown. Since the energy collection subsystem and the power conversion subsystem can function for some time independently on each other in most cases, the operational planning can be further divided into these categories.

The basic operation analyses described here are based on the schematics shown in Figures 4.1-1, 4.1-2, and 4.1-3.

A timeline for a typical days operation of the system is presented on Figure 4.1-9. The emergency shutdown, standby, and extended shutdown modes are not shown on this chart because they are rare and unusual conditions. Operational timelines for these modes are presented when these conditions are discussed in detail in later paragraphs.

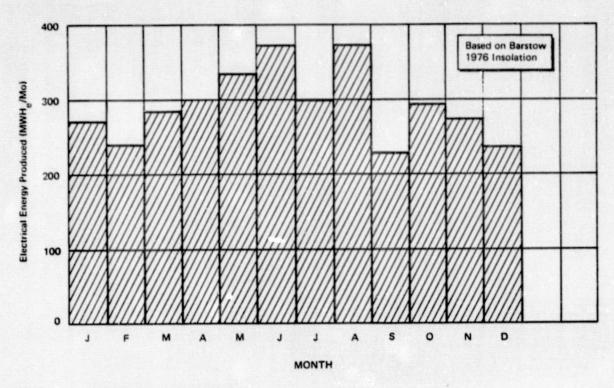


Figure 4.1.-8. Monthly Energy Production

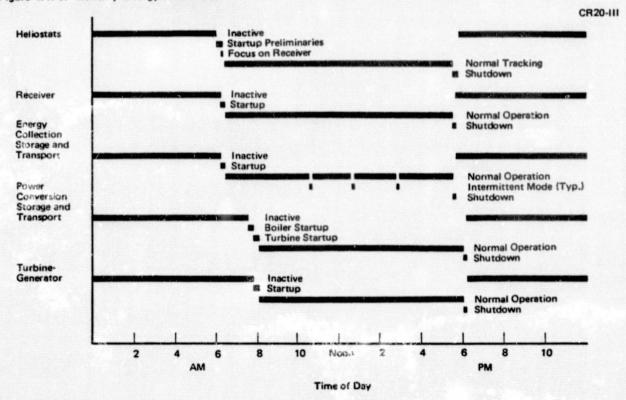
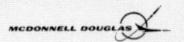


Figure 4.1-9. Operational Timeline - Typical Day



#### 4.1.2.1 Receiver Subsystem

Although the design differences between the 3.5-year, 4.5-year, and 6.5-year programs will result in some variation in physical characteristics between programs and marked differences in other parts of the system, the operational characteristics of the receiver are unaffected by the choice of program duration.

Due to the functional separation of the energy collection and power conversion subsystems, it is possible to operate either loop independently. The energy collection subsystem can be operated with the power conversion subsystem inactive until the thermal storage is completely filled, which will normally require several hours. Accordingly, the operational procedures have been planned on the basis of independent operation of the energy collection and power conversion subsystems, although simultaneous operation of both functions can be accomplished at any time with no impact on the system.

The following paragraphs outline the operational procedures directly related to the receiver. It should be noted that the operation of the receiver loop itself will be described under the energy transport subsystem in Section 4.1.2.3.

#### Startup Mode

Approximately 3 minutes before the initiation of energy collection, the heat transfer fluid (Hitec for the 3.5- and 4.5-year programs and HTS for the 6.5-year program) flow will be initiated and the receiver doors opened. The vent valve at the top of the receiver will be opened at the same time to assist in removal of gas from the receiver and will be closed approximately 1 minute before the initiation of energy collection.

### Normal Operation

During normal operation, the receiver doors will remain open and the receiver vent valve will be closed. The fluid flow through the receiver will be controlled by the energy collection loop of the energy transport subsystem, as described in Section 4.1.2.3.



#### Intermittent Mode

The intermittent mode of operation will result from temporary loss of insolation due to cloud passage. In this mode the flow through the receiver will be reduced to the minimum flow level. The receiver doors will remain open and the receiver will accept the input energy from the concentrator field as soon as insolation returns.

#### Normal Shutdown

Approximately 30 seconds after the termination of energy collection, the heat transfer fluid flow will be terminated and the receiver doors will be closed. The vent valve at the top of the receiver will be opened to permit the fluid to drain into storage and will be closed 5 minutes after the end of energy collection. Additional details of the shutdown are presented in Section 4.1.2.3. Trace heating of the receiver will be enabled but will not be required during overnight shutdown.

## Emergency Shutdown

As a consequence of the functional independence of the energy collection and power conversion subsystems, emergency shutdown will not necessarily involve both subsystems. When the emergency shutdown involves the energy collection subsystem, the Hitec will remain in the receiver for the first 60 seconds to guard against overheating during the heliostat defocusing period. The flow will then be terminated, the receiver doors closed, and normal shutdown carried out. Trace heating of the receiver will maintain it at minimum design temperature if the shutdown lasts for an extended period, which would permit the receiver to cool enough to activate the trace heating thermostat.

## Standby Mode

The receiver and the test of the system may be placed in the standby mode when insolation loss is anticipated to last for several days or when system maintenance, either scheduled or unscheduled, will similarly prevent operation for some time. The fluid will be purged into storage from the receiver using the nitrogen cover gas. After the receiver has been purged for 5 minutes, the vent valve will be closed and the receiver trace heating turned off.

Eight hours before the end of the shutdown period, the receiver trace heating will be turned on again in preparation for restarting the system. The receiver doors will remain closed during the standby period. Additional details of the standby procedure are presented in Section 4.1.2.3.

#### Extended Shutdown

The receiver will be placed in the extended shutdown mode when it is anticipated that the energy collection subsystem will be inoperative for at least 2 weeks. The receiver and its associated lines will be purged of working fluid using the nitrogen cover gas. After the receiver has been purged for 5 minutes, the vent valve will be closed and the receiver trace heating turned off. The receiver doors will remain closed during the extended shutdown unless opened for inspection or maintenance activity. Eight hours before the end of the shutdown period, the receiver trace heating will be activated to bring the receiver up to design operational temperature. Related operations are presented in Section 4.1.2.3.

## 4.1.2.2 Energy Storage Subsystem

The operation of the energy storage subsystem is inherently part of the operation of the energy transport subsystem and is described in the following section.

## 4.1.2.3 Energy Transport Subsystem

Due to the design differences between the 3.5- and 4.5-year programs and the 6.5-year program, the description of the operational characteristics of the energy storage and transport subsystems will be divided into two independent writeups. The first will cover the 3.5-year and 4.5-year programs with two-tank storage and the second will describe the operation of the 6.5-year program using the single tank, dual-media, thermocline storage.

## 3.5-Year and 4.5-Year Programs (Figures 4.1-1 and 4.1-2)

As a consequence of the functional separation of the energy collection and power conversion loops, it is possible to start up, operate, or shut down either loop independently. The energy collection loop can be operated with the power conversion loop inactive until the thermal storage is completely



full, which will normally require several hours. Conversely, the power conversion subsystem can be operated using energy from thermal storage while the energy collection subsystem is not operating. Accordingly, the operational procedures have been planned and described on the basis of independent operation of the energy collection and power conversion loops, with references to any effects of simultaneous operation of both subsystems wherever there is any minor operational difference as a consequence.

Startup Mode Energy Collection Loop--Calculations indicate that the energy collection subsystem should not cool below the freezing point of Hitec during an overnight shutdown, and the use of standard industrial trace heating throughout the system will ensure that longer periods of non-operation will not result in system temperatures that might cause Hitec solidification. An additional benefit as a consequence is that no thermal shock problems should be encountered during startup of the energy collection loop. The configuration of the energy storage and transport subsystems during the startup of the energy collection loop is also discussed in Section 4.6.2, and an operational timeline is presented on Figure 4.1-10.

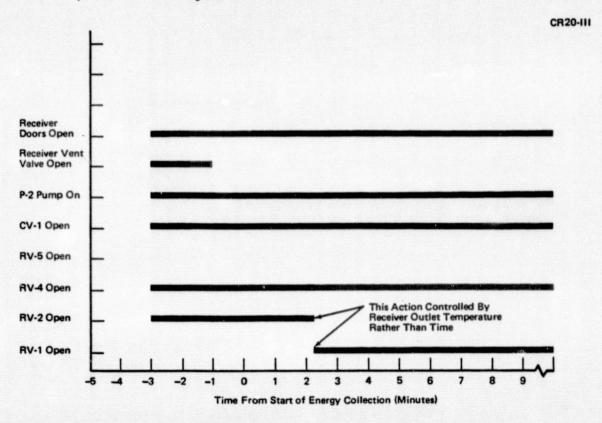


Figure 4.1-10. Operational Timeline — Energy Collection Loop — Startup (3.5 and 4.5-Year Program)

Three minutes before the initiation of energy collection, the Hitec shutoff valves RV-2 and RV-4 will be opened, RV-1 will remain closed, and the control valve CV-1 will be placed in the startup flow position. The Hitec pump P-2 in the cold tank will be started and the flow through the collection loop initiated. During startup the flow returning from the receiver will be directed to the cold tank.

In most cases, energy collection will be initiated before the warmup of the steam generated in the power conversion loop or after the warmup has been completed, so the Hitec shutoff valve RV-5 will be closed. However, if the energy collection startup and the steam generator warmup overlap in time, the RV-5 Hitec shutoff valve will be open during the warmup period. If the steam generator warmup initiation precedes the energy collection startup, the Hitec pump P-2 will already be on when the energy collection startup procedure is initiated.

When the Hitec temperature leaving the receiver reaches the design operating value, the RV-1 valve will be opened and the RV-2 valve will be closed. This will send the Hitec into the hot thermal storage tank.

Startup Mode (Power Conversion Loop)—Approximately 30 minutes before the start of electrical power generation, the Hitec shutoff valves RV-3 and RV-5 will be opened, the Hitec pump P-1 in the hot tank will be started, and the Hitec pump P-2 in the cold tank will be started if it is not already operating to serve the energy collection subsystem. If energy collection is taking place, the Hitec shutoff valve RV-4 will be open; if not, RV-4 will be closed.

The Hitec control valves CV-2 and CV-3 will be modulated to ramp the mixed temperature of the Hitec flow to the steam generator from the trace heating level of 171°C (340°F) to the operating temperature at a rate of 16.7°C/minute (30°F/minute). This should be a conservative rate of warmup since the Southern California Edison Company warms up bottoming-cycle steam generators from 375°F to 1,700°F in 30 minutes with gas turbine exhaust. This corresponds to a rate of 24.5 C/minute (44°F/minute) and is routinely performed on boilers of carbon steel.

As experience is gained with the E.E. No. 1 steam generator, it will probably be possible to shorten the warmup time. The common industrial boiler practice is to increase the warmup rate until there is a noticeable change in the acoustic signature of the boiler and then drop the rate slightly.

At the same time the Hitec flow is initiated, the boiler feedwater pump will be started. The turbine supply shutoff valve will be closed and the turbine bypass valve will be opened. This procedure will ensure that by the time the steam generator reaches operating temperature, the steam supply line to the turbine is warmed to operating temperature all the way to the turbine, thus precluding condensation in the supply lines and its potential damaging consequences for the turbine.

When the steam generator is up to operating temperature, the RV-5 Hitec will be closed. If energy collection is not taking place, the P-2 Hitec pump will be turned off. The configuration of the energy storage and transport subsystems is also discussed in Section 4.6.2, and an operational timeline for startup of the power conversion subsystem is presented on Figure 4.1-11.

Normal Operation (Energy Collection Loop)—When the energy collection loop is in normal operation, the Hitec pump P-2 will draw fluid from the cold storage tank, pump it through the receiver, and return it to the hot storage tank. The Hitec shutoff valves RV-1 and RV-4 will be open, while RV-2 and RV-5 will be closed. The flow rate will be controlled by the Hitec control valve, CV-1 to maintain the receiver exit temperature at the design value. The configuration of the energy storage and transport subsystems is also discussed in Section 4.6.2, and an operational timeline is presented on Figure 4.1-12.

The Hitec shutoff valve RV-5 will remain closed during most of the time the energy collection subsystem is operating. However, the steam generator warm-up will often occur during operation of the energy collection loop, which will require RV-5 to be open during the warmup period.



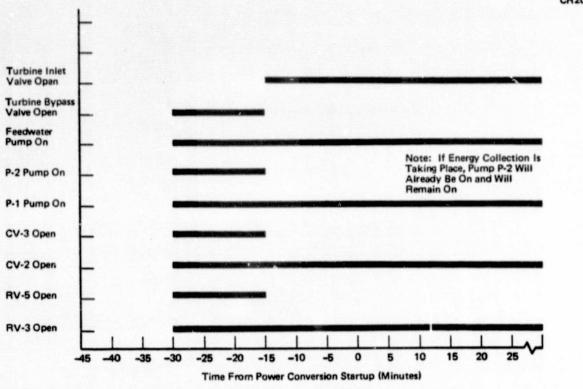


Figure 4.1-11. Operational Timeline - Power Conversion Loop - Startup (3.5 and 4.5-Year Programs)

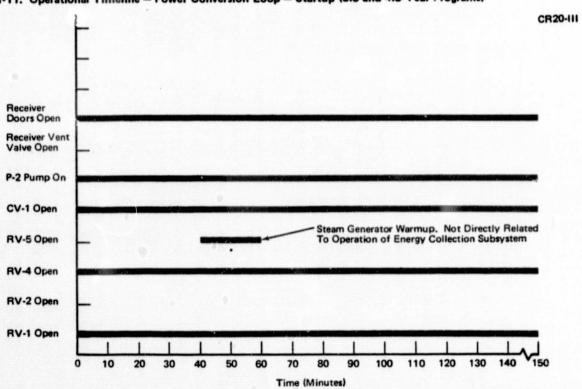


Figure 4.1-12. Operational Timeline - Energy Collection Loop - Normal Operation (3.5 and 4.5-Year Programs)

Normal Operation (Power Conversion Subsystem)—During normal operation of the power conversion loop, Hitec will be drawn from the hot tank by the pump P-1, sent to the steam generator, and returned to the cold tank. The Hitec shutoff valve RV-3 will be open and the control valve CV-2 will modulate the Hitec flow rate to maintain its exit temperature from the steam generator at the design value. The operational configuration of the energy storage and transport subsystems is also discussed in Section 4.6.2 and an operational timeline is presented on Figure 4.1-13.

Intermittent Mode (Energy Collection Loop)—Since the intermittent mode results from a short-duration period without energy collection and the thermal storage system will isolate the power conversion loop from these transients, the power conversion subsystem will not operate in an intermittent mode. The energy collection loop of the energy storage and transport subsystems will be placed into the intermittent mode by opening the Hitec shutoff valve RV-2 and closing the RV-1 valve, thus sending the flow from the receiver into the

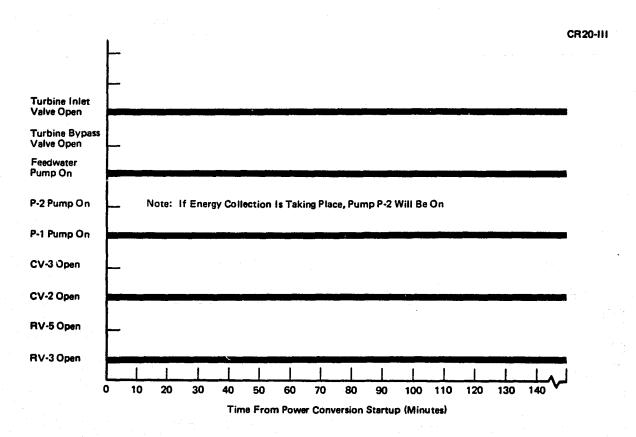


Figure 4.1-13. Operational Timeline - Power Conversion Loop - Normal Operation (3.5 and 4.5-Year Programs)

cold tank. The Hitec control valve will be in the minimum flow position to minimize the parasitic power losses, the RV-4 shutoff valve will remain open, and the Hitec pump P-2 will remain operating to ensure against the possibility of overheating the receiver when insolation returns. The configuration of the subsystems with power conversion operating from storage and the energy collection loop in the intermittent mode is also discussed in Section 4.6.2 and an operational timeline is presented on Figure 4.1-14.

Normal Shutdown (Energy Collection Loop)—Thirty seconds after the shutdown of the energy collection subsystem is initiated, the Hitec pump P-2 will be turned off, thus terminating flow through the receiver. The Hitec shutoff valve RV-4 and the Hitec control valve CV-1 will be left open, RV-1 will be closed, and RV-2 opened. As described in Section 4.1.2.1, the vent valve at the top of the receiver will be opened to permit the Hitec in the energy collection loop to drain into storage in the cold tank. Five minutes after the energy collection shutdown is initiated, all valves in the energy collection subsystem will be closed. Trace heating of the subsystem lines and hard-

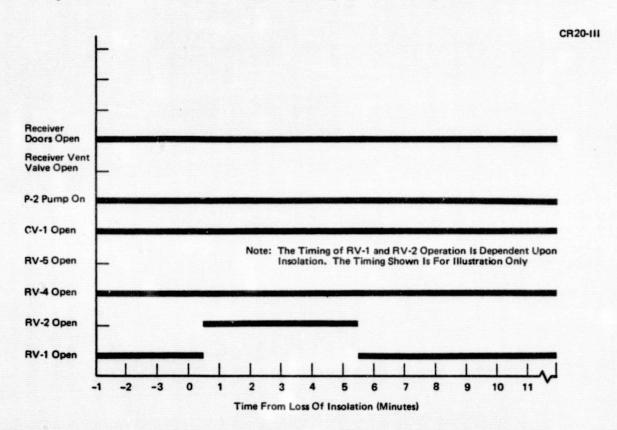


Figure 4.1-14. Operational Timeline - Energy Collection Loop, Intermittent Mode (3.5 and 4.5-Year Programs)

ware will be available to maintain the equipment at design temperature, although it is not expected to be required on most of the system during a normal overnight shutdown.

The configuration of the energy storage and transport subsystems is also discussed in Section 4.6.2, and the operational timeline for shutdown of the energy collection subsystem is presented on Figure 4.1-15.

Normal Shutdown (Power Conversion Loop)—Although the power conversion subsystem and energy collection subsystem can be shutoff simultaneously if desired, in most cases they will be shutdown at different times. Accordingly, the operational timeline presented on Figure 4.1-16 is referenced to a shutdown command for the power conversion subsystem. Shutdown can be initiated as desired or automatically upon depletion of the Hitec in the hot storage tank.

When shutdown of the power conversion subsystem is initiated, the Hitec pump P-1 will be turned off, the Hitec shutoff valve RV-3 will be closed, the steam generator feedwater pump will be turned off, the feedwater valve closed, the turbine steam bypass valve opened, and the turbine steam inlet valve closed. Trace heating of the Hitec lines and hardware will be thermostatically controlled as necessary to maintain temperatures above the melting point of Hitec during the shutdown period.

Emergency Shutdown (Energy Collection Loop)—As a consequence of the functional separation of the energy collection and power conversion subsystems, emergency shutdown may be required of only one of the loops in many cases, rather than always involving shutdown of the entire plant. The operational timeline for emergency shutdown of the energy collection subsystem is presented on Figure 4.1-17 and the operational configuration, which will be identical to the normal shutdown configuration, is also discussed in Section 4.6.2.

When emergency shutdown is initiated the Hitec pump P-2 will immediately be turned off, the Hitec control valve CV-1 will be opened fully, the Hitec shutoff valve RV-2 will be opened, and RV-1 will be closed. Fifteen seconds later the vent valve at the top of the receiver will be opened to permit the



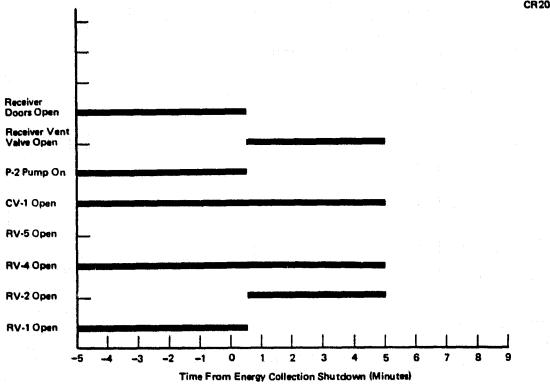


Figure 4.1-15. Operational Timeline — Energy Collection Loop — Normal Shutdown (3.5 and 4.5-Year Programs)



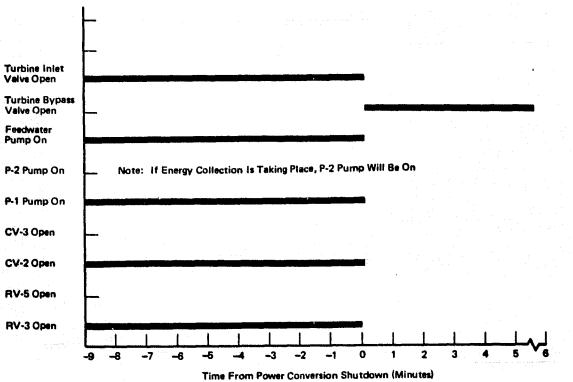


Figure 4.1-16. Operational Timeline - Power Conversion Loop - Normal Shutdown (3.5 and 4.5-Year Programs)





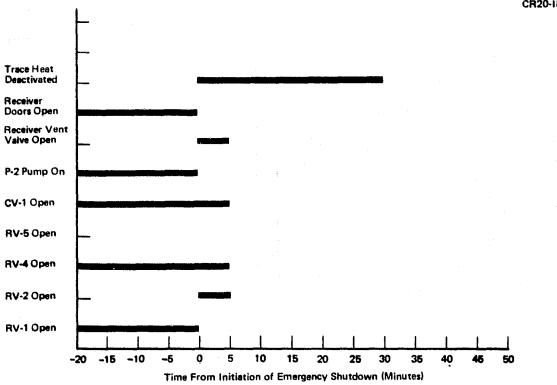


Figure 4.1-17. Operational Timeline - Energy Collection Loop - Emergency Shutdown (3.5 and 4.5-Year Programs)

Hitec to drain into storage in the cold tank. Five minutes after the initiation of emergency shutdown the receiver vent valve and all Hitec valves in the energy collection loop will be closed.

Trace heating of the Hitec lines and hardware will be deactivated until thirty minutes after the shutdown is initiated. This will permit time to cut the power supply to the trace heating system in the event that electrical problems in the trace heating were the cause of the shutdown, but will not result in any adverse impact upon the system if other problems caused the shutdown, since the equipment will not cool enough to activate the trace heating thermostat during this period anyway.

Emergency Shutdown (Power Conversion Loop) -- When an emergency shutdown of the power conversion subsystem is initiated the Hitec pump P-1 will be turned off, the shutoff valve RV-3 closed, the steam generator feedwater pump turned off, the feedwater valve closed, the turbine steam bypass valve opened, and the turbine steam inlet valve closed.



Trace heating of the Hitec lines and hardware will be deactivated until thirty minutes after the shutdown is initiated. This will permit time to cut the power supply to the trace heating system in the event that electrical problems in the trace heating were responsible for the shutdown, but will not result in any adverse impact upon the system if other problems caused the shutdown, since the equipment will not cool enough to activate the trace heating thermostat during this period in any event.

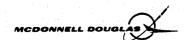
Standby Mode--The energy storage and transport subsystems may be placed in the standby mode, along with the rest of the system, if insolation loss is anticipated to last for several days or when plant maintenance will similarly prevent operation. The Hitec control valve CV-1 and the shutoff valves RV-2 and RV-4 will be opened and RV-1 will be closed. The vent valve at the top of the receiver will be opened and the Hitec in the energy collection loop purged into storage in the cold tank.

Trace heating of the system lines and hardware will be turned off until eight hours before the end of the standby period. The immersion heaters in the thermal storage tanks will maintain the Hitec above its melting point if the duration of the standby period is sufficient to allow the Hitec to cool enough to require heating.

Extended Shutdown--The system will be placed in an extended shutdown mode when it is anticipated that the system will be inoperative for at least two weeks. The extended shutdown mode will be identical to the standby mode except that the thermal storage tank immersion heaters will be turned off to save energy. One week prior to the end of the shutdown period the immersion heaters will be turned on to melt any Hitec that may have solidified.

# 6.5-Year Program (Figure 4.1-3)

As a consequence of the functional separation of the energy collection and power conversion subsystems, it will be possible to startup, operate, or shutdown either subsystem loop independently in most cases. The energy collection subsystem can be operated with the power conversion subsystem inactive until the thermal storage is completely full, which normally will require



several hours. Conversely, the power conversion system can be operated using energy from thermal storage while the energy collection subsystem is not operating.

Accordingly, the operational procedures have been planned and described on the basis of independent operation of the energy collection and power conversion subsystems, with references to any effects of simultaneous operation of both subsystems whenever there is any minor operation difference as a consequence.

Startup Mode (Energy Collection Loop)—The use of standard industrial trace heating throughout the system will ensure that no HTS solidification will occur during periods of non-operation. An additional benefit as a consequence is that no thermal shock problems should occur during startup of the energy collection loop. The configuration of the energy storage and transport systems during the startup of the energy collection subsystem is also discussed in Section 4.6.2 and an operational timeline is presented on Figure 4.1-18.

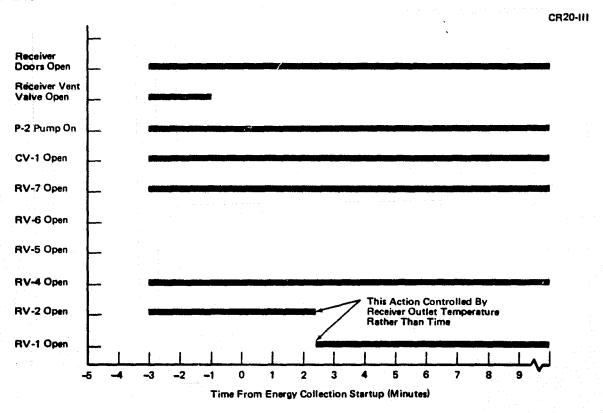


Figure 4.1-18. Operational Timeline — Energy Collection Loop — Startup (6.5-Year Program)



Three minutes prior to the start of energy collection the HTS shutoff valves RV-2, RV-4, and RV-7 will be opened and the HTS control valve CV-1 will be placed in the startup flow position. RV-1 and RV-5 will remain closed and the HTS pump P-2 will be turned on.

In most cases energy collection will be initiated prior to the steam generator warmup or after the warmup has been completed, so the Hitec shutoff valve RV-6 will remain closed. However if the energy collection startup and the steam generator warmup periods overlap, the RV-6 shutoff valve may be open and the P-2 pump might already by operating. When the HTS temperature leaving the receiver reaches the design operating value, RV-1 will be opened and RV-2 will be closed, thus directing the hot HTS to the top of the tank.

Startup Mode (Power Conversion Loop) -- Thirty minutes prior to the start of electrical power generation the HTS shutoff valves RV-3, RV-6, RV-7, and RV-8 will be opened and the HTS pumps P-1 and P-2 will be started. If energy collection is taking place RV-4 will be open and P-2 may already be in operation. If not, RV-4 will remain closed.

The HTS control valves CV-1 and CV-2 will be modulated to ramp the mixed temperature of the HTS flow to the steam generator from the trace heating value of 288°C (550°F) to the operating temperature at a rate of 16.7°C/minute (30°F/minute). This should be a conservative rate of warmup since the Southern California Edison Company routinely warms up bottoming-cycle steam generators from 375°F to 1,700°F in thirty minutes with gas turbine exhaust, which corresponds to a rate of 24.5°C/minute (44°F/minute). The operational configuration during power conversion startup is also discussed in Section 4.6.2 and an operational timeline is presented on Figure 4.1-19.

As experience is gained with the E.E. No. 1 steam generator it will probably be possible to shorten the warmup time. The common industrial boiler practice is to increase the warmup rate until there is a noticeable change in the acoustic signature of the boiler and then drop the rate slightly.

At the same time the HTS flow is initiated, the boiler feedwater pump will be started. The turbine supply shutoff valve will be closed and the turbine

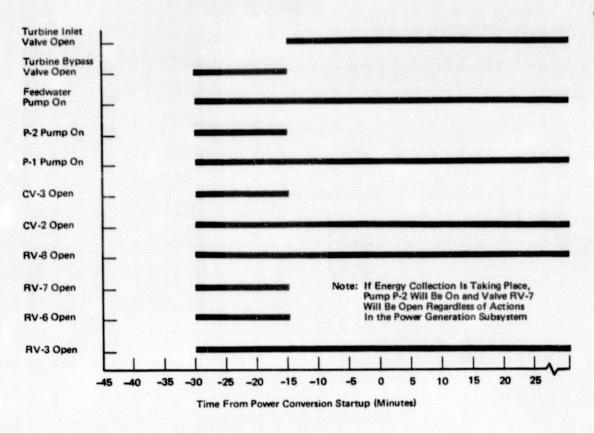


Figure 4.1-19. Operational Timeline — Power Conversion Loop — Startup (6.5-Year Program)

bypass valve will be opened. This procedure will ensure that by the time the steam generator reaches operating temperature the steam supply line to the turbine is warmed to operating temperature all the way to the turbine, thus precluding condensation in the supply lines and its potential damaging consequences for the turbine.

When the steam generator is up to operating temperature the RV-6 HTS valve will be closed. If energy collection is not taking place, the P-2 HTS pump will be turned off. The configuration of the energy storage and transport subsystems is also covered in Section 4.6.2.

Normal Operation (Energy Collection Loop) -- When the energy collection loop is in normal operation, the Hitec pump P-2 will draw fluid from the bottom of the tank, pump it through the receiver, and return it to the top of the tank. The Hitec shutoff valves RV-1, RV-4 and RV-7 will be open, while RV-2 and

RV-5 will be closed. The flow rate will be controlled by the Hitec control valve CV-1 to maintain the receiver exit temperature at the design value. The configuration of the energy storage and transport subsystems is also covered in Section 4.6.2 and an operational timeline is presented on Figure 4.1-20.

The Hitec shutoff valve RV-6 will remain closed during most of the time the energy collection subsystem is operating. However, the steam generator warm-up will often occur during operation of the energy collection loop, which will require RV-6 to be open during the warmup period.

Normal Operation (Power Conversion Loop)—During normal operation of the power conversion loop HTS will be drawn from the top of the tank by the pump P-1, sent to the steam generator and returned to the bottom of the tank. The HTS shutoff valves RV-3 and RV-8 will be open and the control valve CV-2 will modulate the HTS flow rate to maintain its exit temperature from the steam generator at the design value. The operational configuration of the energy storage and transport subsystems is also described in Section 4.6.2 and an operational timeline is presented on Figure 4.1-21.

Intermittent Mode (Energy Collection Loop)—Since the intermittent mode results from a short-duration period without energy collection and the thermal storage system will isolate the power conversion loop from these transients, the power conversion subsystem will not operate in an intermittent mode. The energy collection loop of the energy storage and transport subsystems will be placed into the intermittent mode by opening the HTS shutoff valve RV-2 and closing the RV-1 valve, thus sending the flow from the receiver into the cold tank. The HTS control valve CV-1 will be in the minimum flow position to minimize the parasitic power losses, the RV-4 and RV-7 values will remain open, and the HTS pump P-2 will remain operating to insure against the possibility of overheating the receiver when insolation returns. The configuration of the subsystems with power conversion operating from storage and the energy collection loop in the intermittent mode is also discussed in Section 4.6.2 and an operational timeline is presented on Figure 4.1-22.

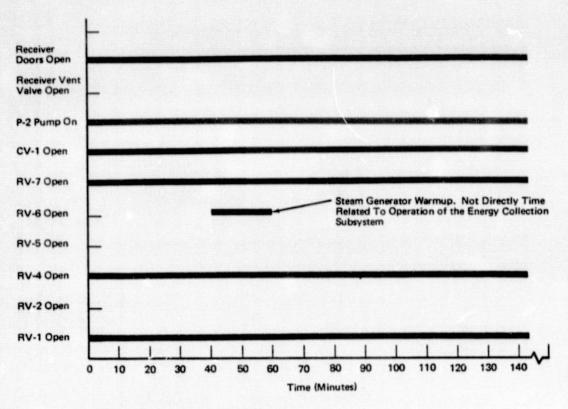


Figure 4.1-20. Operational Timeline — Energy Collection Loop — Normal Operation (6.5-Year Program)

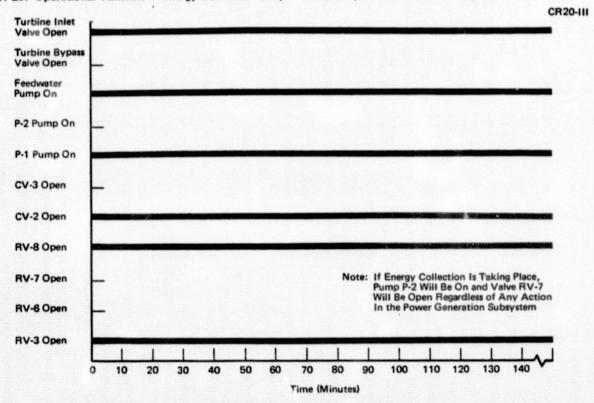
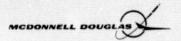


Figure 4.1-21. Operational Timeline - Power Conversion Loop - Normal Operation (6.5-Year Program)





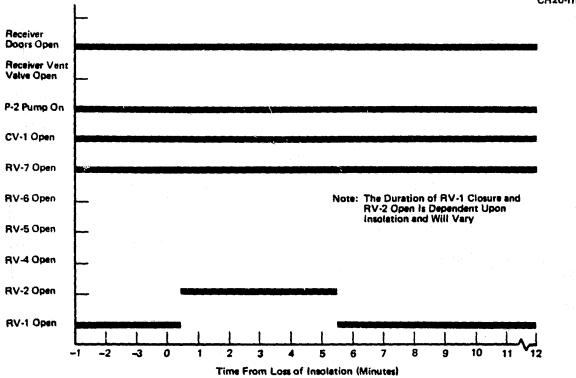


Figure 4.1-22. Operational Timeline - Energy Collection Loop - Intermittent Mode (6.5-Year Program)

Normal Shutdown (Energy Collection Loop)—Thirty seconds after the shutdown of the energy collection subsystem is initiated the HTS pump P-2 will be turned off, thus terminating flow through the receiver. The HTS shutoff valve RV-7 and the HTS control valve CV-1 will be left open, RV-1 and RV-4 will be closed, and RV-5 opened. As described in Section 4.1.2.1, the vent valve at the top of the receiver will be opened to permit the HTS in the energy collection loop to draw into storage in the bottom of the tank. Five minutes after the energy collection shutdown is initiated all valves in the energy collection subsystem will be closed. Trace heating of the subsystem lines and hardware will be available to maintain the equipment at design tempera ture, although it is not expected to be required on most of the system during a normal overnight shutdown.

The configuration of the energy storage and transport subsystems is also discussed in Section 4.6.2 and the operational timeline for shutdown of the energy collection loop is presented on Figure 4.1-23.



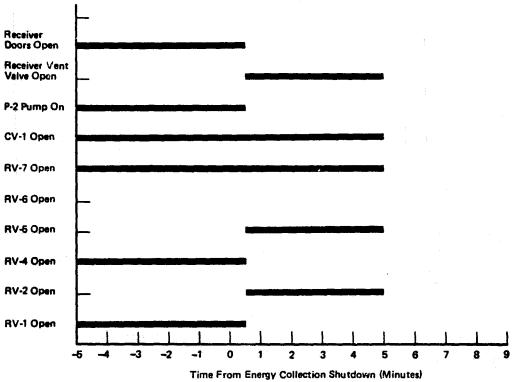


Figure 4.1-23. Operational Timeline — Energy Collection Loop — Normal Shutdown (6.5-Year Program)

Normal Shutdown (Power Conversion Loop)—Although the power conversion subsystem and energy collection subsystem can be shutoff simultaneously if desired, in most cases they will be shutdown at different times. Accordingly, the operational timeline presented on Figure 4.1-24 is referenced to a shutdown command for the power conversion subsystem. Shutdown can be initiated as desired or automatically upon the bottom of the thermocline reaching the top of the tank.

When shutdown of the power conversion subsystem is initiated the HTS pump P-1 will be turned off, the HTS shutoff valves RV-3 and RV-8 will be closed, the steam generator feedwater pump will be turned off, the feedwater valve closed, the turbine steam bypass valve opened, and the turbine steam inlet valve closed. Trace heating of the HTS lines and hardware will be thermostatically controlled as necessary to maintain temperatures above the melting point of HTS during the shutdown period.



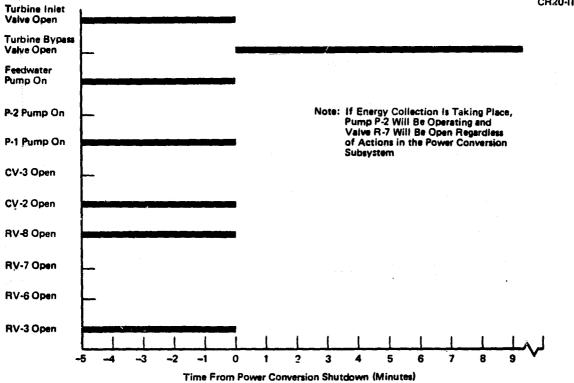


Figure 4.1-24. Operational Timeline -- Power Conversion Loop -- Normal Shutdown (6.5-Year Program)

Emergency Shutdown (Energy Collection Loop)—As a consequence of the functional separation of the energy collection and power conversion subsystems, emergency shutdown may be required of only one of the loops in many cases, rather than always involving shutdown of the entire plant. The operational timeline for emergency shutdown of the energy collection loop is presented on Figure 4.1-25 and the operational configuration will be identical to the normal shutdown configuration.

When emergency shutdown is initiated the HTS pump P-2 will immediately be turned off, the HTS control valve CV-1 will be opened fully, the HTS shutoff valve RV-2 and RV-5 will be opened, and RV-1 and RV-4 will be closed. Fifteen seconds later the vent valve at the top of the receiver will be opened to permit the HTS to drain into storage in the bottom of the tank. Five minutes after the initiation of emergency shutdown the receiver vent valve and all HTS valves in the energy collection loop will be closed. Trace heating of the HTS lines and hardware will be deactivated until thirty minutes after the shutdown is initiated. This will permit time to cut the power supply to the



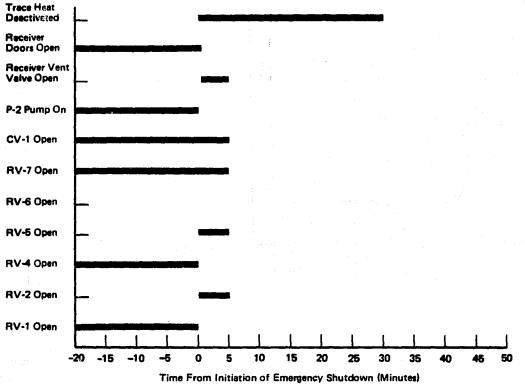


Figure 4.1-25. Operational Timeline — Energy Collection Loop — Emergency Shutdown (6.5-Year Program)

trace heating system in the event that electrical problems in the trace heating were the cause of the shutdown, but will not result in any adverse impact upon the system if other problems caused the shutdown, since the equipment will not cool enough to activate the trace heating thermostat during this period anyway.

Emergency Shutdown (Power Conversion Loop)— When an emergency shutdown of the power conversion subsystem is initiated the HTS pump P-1 will be turned off, the shutoff valves RV-3 and RV-8 closed, the steam generator feedwater pump turned off, the feedwater valve closed, the turbine steam bypass valve opened, and the turbine steam inlet valve closed.

Trace heating of the HTS lines and hardware will be deactivated until thirty minutes after the shutdown is initiated. This will permit time to cut the power supply to the trace heating system in the event that electrical problems in the trace heating were responsible for the shutdown, but will not result in any adverse impact upon the system if other problems caused the

shutdown, since the equipment will not cool enough to activate the trace heating thermostat during this period in any event.

Standby Mode--The energy storage and transport subsystems may be placed in the standby mode, along with the rest of the system, if insolation loss is anticipated to last for several days or when plant maintenance will similarly prevent operation. The HTS control valve CV-1 and the shutoff valves RV-2, RV-5, and RV-7 will be opened, and RV-1 and RV-4 will be closed. The vent valve at the top of the receiver will be opened and any HTS in the energy collection loop purged into storage in the cold tank.

Trace heating of the system lines and hardware will be turned off until eight hours before the end of the standby period. The immersion heater in the thermal storage tank will maintain the HTS above its melting point if the duration of the standby period is sufficient to allow the HTS to cool enough to require heating.

Extended Shutdown—The system will be placed in an extended shutdown mode when it is anticipated that the system will be inoperative for at least two weeks. The extended shutdown mode will be identical to the standby mode except that the thermal storage tank immersion heaters will be turned off to save energy. One week prior to the end of the shutdown period the immersion heaters will be turned on to melt any HTS which may have solidified.

#### 4.1.2.4 Power Conversion Subsystem

Since the turbine-generator subsystem operational procedures are specified by the manufacturer and vary slightly between different manufacturers and units, it is not possible to establish from operational procedures until later in the program. However, the following operational procedures should be typical and can be updated when a turbine-generator unit is chosen. In the case of the ETI radial turbine which is planned for use in the 6.5-year program, the turbine operational procedures may change somewhat as development proceeds.

As a result of the ability of the power conversion subsystem and the energy collection subsystem to operate independent of each other for some time in



most cases, the operational procedures have been planned and described on the basis of independent operation of the two loops. Simultaneous initiation of the power conversion and energy collection subsystems commands can be accomplished if desired.

## Startup Mode

Although the details of the turbine startup will vary slightly between manufacturers, the basic procedure should be similar to the following outline given in a turbine operation manual. As a nominal design value it will be assumed that the turbine will be started and brought to full operating speed in 15 minutes. This would appear to be a good initial operational schedule since 1.7 megawatt marine steam turbines in use on U.S. Navy aircraft carriers are routinely brought on line in 15 minutes.

As experience is gained with the E.E. No. 1 turbine it may be possible to shorten the startup time. The common industrial practice is to control the rate of speed increase by monitoring the turbine vibration, which is considered indicative of the thermal conditions inside the turbine. The following preparation and startup sequence would be followed.

- 1. Open the shutoff valves in the steam supply lines
- 2. Drain off any water in the bottom of the oil tank
- 3. Check the level in the oil tank. (Oil level sight glass)
- 4. Check that the turbine governor switch and the electric heater switch are in the "ON" position. Start the electric driven oil pump. (Carried out at the turbine terminal box.)

The gear casing heater then shuts off automatically. (Oil pressure = 0.2 bar gauge) and the oil temperature begins to increase slowly.

- 5. Open the cooling-water supply valves to and from the oil cooler. (The oil temperature is controlled by the oil cooler automatic bypass valve.)
- 6. Check that the inlet and exhaust steam conditions are close to normal for start (see instruments). (The turbine cannot be started if the exhaust pressure is too high.)
- 7. Check that the drain valves in the steam lines and on the turbine are open. (Drain line from the emergency cutout valve.)



8. Open the valve in the exhaust line.

- Adjust the flow of packing steam until there is only a slight leakage at each end of the turbine casing.
- 9. Open the valve in the gland steam extraction line. (There must be no visible steam leakage at the ends of the turbine casing.)
- 10. Check the function of the overspeed and axial displacement trip by operating manually. Reset the trip mechanism.
- 11. Check that the steam in the supply line is close to operating temperature.

Shut off the drain valves when the steam is dry.

12. Run both speed adjusters to the minimum position. (Coarse speed adjustment decrease button, and fine speed adjustment switch, decrease position.) (Carried out from the control room.)

Reset the trip system. (Carried out at the turbine governing box.)

- 13. The oil temperature, measured after the oil cooler, must be at least 20 degrees C. If not, the oil must be heated.
- 14. Start the turbine carefully by opening the emergency cutout valve. Check that the governing system assumes control when the speed is 10 to 15 per cent of normal. (This will be apparent by observing the governing oil pressure and the governing valve.) Lock the emergency stop valve in open position.
- 15. The following conditions must be met before the speed may be increased further.
- a. The turbine must have run at 10 to 15 per cent of speed for at least 10 minutes.
- b. The oil temperature must be at least 30 degrees C after the oil cooler.
- 16. Gradually increase the speed with the coards speed adjuster. (Total speed increase time must not be less than one minute) to 90% speed.

Check that the direct driven oil pump takes over and that the electric pump stops. (The electric pump is thereafter on standby duty.)

17. Increase the speed with the fine speed adjuster and synchronize the generator to the network. (Carried out from the control room.)

## Normal Operation

In normal operation the turbine will receive high pressure - high temperature steam from the steam generator. The steam will deliver energy to the turbine and be exhausted to the condenser.

### Normal Shutdown

Since the power generation and energy collection functions are separate, either loop can be shutdown without immediately affecting the other loop in most cases. Therefore the assumption is made that energy collection shutdown is initiated at a different time, since this will be the normal case. Simultaneous shutdown of both loops can be accomplished if desired or necessary but is normally not required.

Although the details of a normal turbine shutdown will vary slightly between manufacturers, the basic procedure should follow the general outline given as follows.

- 1. Reduce the load on the generator and open the generator breaker.
- 2. Stop the turbine by pressing the stop button. Check that the electric oil pump starts.
  - 3. Shut the emergency cutout valve and lock it.
- 4. Shut the valves in the exhaust line, gland steam extraction line and packing steam supply line.
  - Shut the valves in the steam supply line.
  - 6. Open the drain valves in the steam lines and on the turbine.
  - 7. Shut off the supply of cooling water to the oil cooler.
- 8. Stop the electric oil pump after about one hour of operation. Check that the gear casing heater is on.

## **Emergency Shutdown**

Emergency shutdown of the power generation loop can be accomplished without any immediate need to shut down the energy collection loop in most cases, since the energy collection and power generation functions are separate.



Consequently the shutdown procedure will be planned on the assumption that energy collection will be initiated at a different time, since this will be the normal case. This will not prevent simultaneous shutdown of both loops if desired or necessary.

An emergency shutdown of the turbine-generator package can be initiated either by a signal from the system monitor, manual command, or by an abnormality in the turbine. The turbine will have automatic shutdown provisions to protect it in the event of trouble such as turbine overspeed, excessive exhaust pressure, loss of lubricating oil pressure, and excessive vibration. Implementation of the emergency shutdown will vary slightly depending upon the turbine manufacturer but typically will be accomplished by removing oil pressure from a normally-closed shutoff valve in the turbine inlet steam line. The basic procedure should be similar to the following outline:

- 1. Reduce the load on the generator and open the generator breaker.
- 2. Stop the turbine by pressing the stop button. Check that the electric oil pump starts.
  - 3. Shut the emergency cutout valve and lock it.
- 4. Shut the valves in the exhaust line, gland steam extraction line and packing steam supply line.
  - 5. Shut the valves in the steam supply line.
  - Open the drain valves in the steam lines and on the turbine.
  - 7. Shut off the supply of cooling water to the oil cooler.
- 8. Stop the electric oil pump after about one hour of operation. Check that the gear casing heater is on.

#### Standby Mode

In the standby mode the turbine will be shut down except for any trace heating requirements specified by the turbine manufacturer. These might include lubrication oil heaters and gear case heaters.

### Extended Shutdown

In the extended shutdown mode all turbine subsystems will be inoperative until approximately 24 hours prior to the next startup. At that time any required



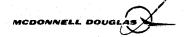
gear case and lube oil heaters should be turned on. During extended shutdown the opportunity should be taken to perform periodic maintenance as recommended by the manufacturer.

## 4.1.3 System Safety Characteristics

The System Safety Analysis of a solar thermal power plant must be concerned with two general areas of safety, the conventional industrial or occupational safety controlled by law in various state and federal statues and the specific hazards which are unique to a solar power plant. The small power system experiment presents three areas of concern with the use of heliostats and HITEC molten salt as a heat transport fluid. These topics are reviewed in the following sections. The safety aspects associated with installation and maintenance are treated in Sections 5.5 and 6.4, respectively.

#### 4.1.3.1 General Requirements

The general safety requirement is to provide a safe power plant for operating personnel and for the general public. The specific requirements include the applicable Occupational Safety and Health Administration (OSHA) regulations of the Federal Government (Title 29 Chapter XVII Part 1910 for operations and Part 1926 for construction) and/or the OSHA regulations of the specific state where the facility is located. If the facility is located in California, for example, the State of California and the Federal Government have agreed that the California Division of Industrial Safety will monitor and control OSHA standards for industry in the State of California. Other specific requirements will include the American National Standards Institute (ANSI) requirements (ANSI C2-1973 National Electrical Safety Code, etc.), the National Fire Protection Association (NFPA) requirements (NFPA 70-1978 National Electrical Code), standards of the National Electrical Manufacturers Association, (NEMA), ASME Boiler and Pressure Vessel Code, Sections I, II, V, VIII and IX and other ANSI and NFPA codes concerning automatic fire detectors, air conditioning systems, blower and exhaust systems, water cooling towers, hazardous chemical handling, elevators, building design loads, mobile ladder stands and scaffolds, mechanical power transmission apparatus, overhead cranes, etc., and the building codes of the specific locality. Air pollution criteria and water release regulations will also be determined by local authorities.



The eye protection criteria for exposure to visible light, developed by the U.S. Army Environmental Hygiene Agency (Reference 4-1), will be utilized until appropriate Federal or State agencies publish a criteria.

#### 4.1.3.2 Heliostat Hazards

Some of the speific potential heliostat safety problems or hazards that have been identified to date by analysis and the heliostat test program at China Lake, California, include electrical shock, interaction with heliostat structure or moving parts, maintenance induced hazards and the reflected beam hazards.

The major potential safety problem is the hazard to personnel (eyes, skin), the environment (brush fires), and the general public from the reflected beams from the heliostats. The solution of these problems is to determine the magnitude of the problems by analysis and then impose specific operational procedures to assure no injury to personnel or the public will occur and equipment and the environment is protected. Beam hazard analysis is discussed in detail in Section 4.1.3.3.

The electrical shock hazard will derive from personnel contact with exposed wires or terminals. The control for this problem will be adherence to the several electrical codes, proper maintenance procedures, personnel training, and proper human engineering of the appropriate equipment.

The general class of interaction of personnel with heliostat structure includes injury to personnel from moving components (actuator screw mechanisms) and from the heliostat mirror panel. Protection from entanglement of fingers, clothing, etc., into the heliostat mechanisms will take the form of protective screens, training, and procedures. Injury to personnel or equipment (maintenance vehicles) from the normal automatic movement of the heliostats is possible in spite of the slow movement (15 /min. maximum). Again, training and procedures are the control methods. Failure of heliostat components could cause rapid movement of the heliostat and/or falling objects (sections of structure, glass, etc.).

<sup>\*</sup>Section 4 references are listed at the end of the section.

Maintenance-induced failures fall into several categories. Automatic remotely controlled movement of the heliostat during maintenance operations could cause personal injury. A safety system which will allow (and be required to procedures) the maintenance personnel to disconnect the individual heliostat from remote control and assume local control of heliostat movement will be provided. When work platforms above ground level are required, they will have railings as detailed by OSHA standards. When lifting or holding devices are used in maintenance (to hold the heliostat in position when actuator maintenance is performed), they will be designed to prevent inadvertent release or structural failure. Adequate training and procedures are also necessary.

The use of cleaning fluids may present specific problems to personnel, the public or the environment which must be analyzed. These problems must be coordinated with the appropriate governmental air quality and water quality agencies.

The presence of extreme environmental conditions (high winds, earthquake, lightning, etc.) can cause potential safety problems. Specific safety procedures (heliostat in stow position during high winds, etc.) will be used in addition to appropriate safety equipment (lightning rods).

#### 4.1.3.3 Beam Hazards

A potential hazard of a solar facility is the hazard to personnel, equipment and the general public from the reflected beams from the heliostats. The solution to this problem is to determine the magnitude of the problem by analysis and then impose specific operational procedures to assure no injury to personnel or the public will occur and that equipment and the environment are protected.

The potential hazards from reflected beams can be divided into hazards from a single heliostat and from multiple heliostats. The magnitude of the reflected beam hazard will be a function of heliostat parameters (reflectivity, size, focal length, beam divergence and tracking errors), field configuration (area density) and the distance from the heliostats. The intensity from a single 49 m<sup>2</sup> heliostat is shown in Figure 4.1-26 as a function of distance. In

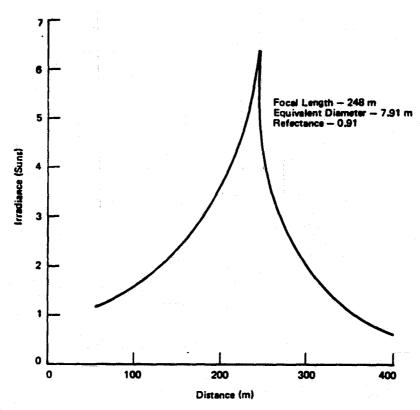


Figure 4.1-26. Heliostat Beam

order to determine the intensity from multiple heliostats, simply multiply the intensity shown in Figure 4.1-26 by the number of heliostats of which beams converge. As can be seen in the figure, the intensity from a single heliostat can be higher than 1 sun. This is typical of heliostats with short focal lengths.

The hazards from these coincident beams on equipment will vary with the specific materials used. An irradiance of about 5 to 10 suns is required to initiate combustion in brush. The potential hazard for skin burns is a function of the time that an individual would spend in the beam. The damage (burn) threshold varies from about 20 suns  $(2.2 \text{ watts/cm}^2)$  to about 140 suns  $(15 \text{ watts/cm}^2)$  at 1 second (Reference 4-2).

The maximum safe exposure level of the human eye to high intensity light depends on the wavelengths, source angle, and duration of exposure. For direct sunlight, the lowest intensity damage threshold is set by damage to the retina. While no official high intensity criteria has been established,



a maximum permissible exposure (MPE) has been set by the U.S. Army Environmental Hygiene Agency (Reference 4-1) which is a function of retinal image size. This criteria is shown in Figure 4.1-27. The retinal irradiance for the typical heliostat is about 4.70 watts/cm $^2$ . The retinal diameter is a function of distance from the heliostat and peaks at 541  $\mu m$  at a distance of 814 m (the focal length of the heliostat). The relationship of these parameter to the criteria is shown in Figure 4.1-28 and, as can be seen, the beam from one heliostat is above the maximum permissible exposure limit. Therefore, it is obvious that some sort of beam control technique for start-up and shutdown will be required to limit the individual personnel exposure or to minimize the personnel exclusion areas on the ground or in the airspace above the collector field.

If a method is used whereby all heliostats are controlled to limit the number of coincident beams, the results of Figures 4.1-26 and 4.1-28 would be used to determine safe distances of exclusion areas.

A beam convergence/divergence method can be used where groups of heliostats are brought up to the receiver (or brought down to the ground) simultaneously by "sliding" them up (or down) an imaginary wire stretched from the receiver to the ground. This method takes advantage of the fact that the beams will diverge beyond the aimpoint and a maximum elevation angle is established. The maximum elevation angle will be that angle which has an aimpoint slightly above the receiver to allow for emergency slew upwards.

This method, developed by T. D. Brumleve (Reference 4-3), would result in a "safe" altitude at about twice the height of the receiver (40 m), or 80 m. This is well below the lowest FAA regulation altitude (500 ft).

#### 4.1.3.4 HITEC Hazards

The principal hazards associated with HITEC heat transfer salt apply to any operation that involves elevated temperature liquids. Adequate precautions should be taken to protect operating personnel from burns in case of equipment failure. There is some danger that HITEC, by supporting the combustion of other materials, may escalate an existing fire hazard.



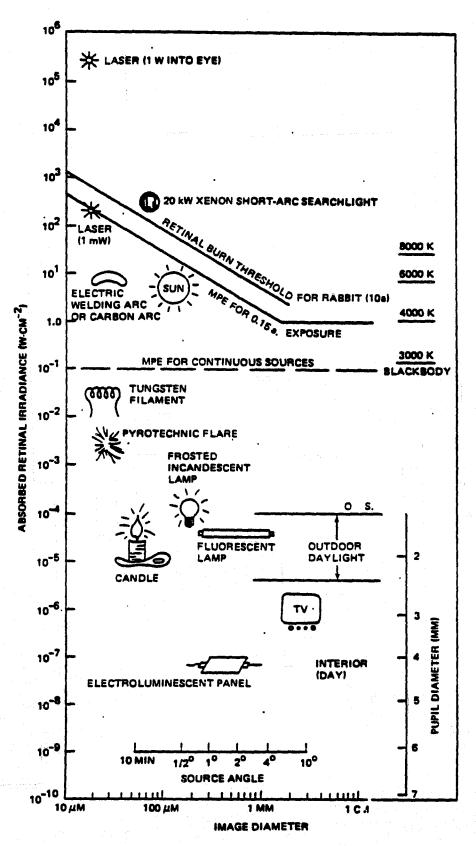


Figure 4.1-27. Absorbed Retinal Irradiance

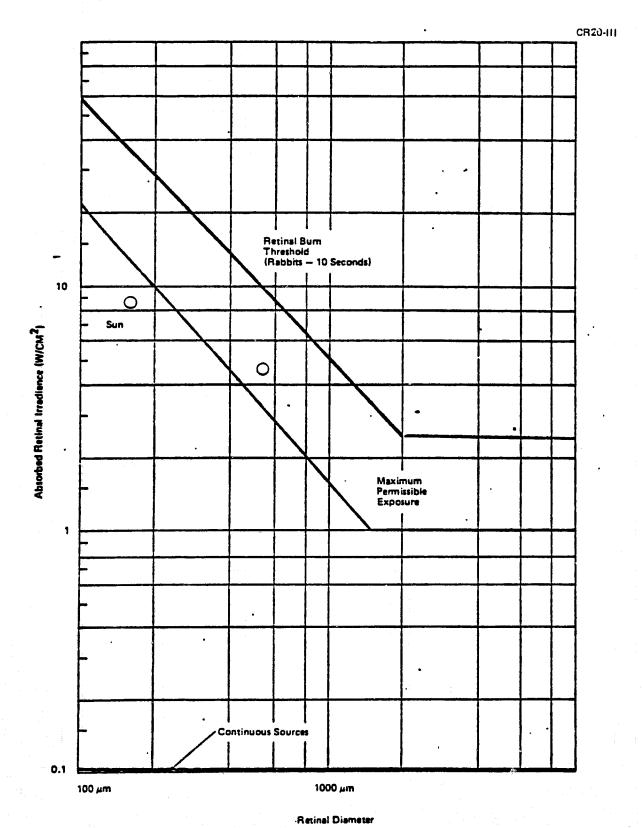


Figure 4.1-28. Retinal Burn Threshold Safety Exposure

MCDONNELL DOUGLAS

Although HITEC is nonflammable, it is a strong oxidizer and supports the combustion of other materials. Contamination of the work area with HITEC may increase any fire hazard created by combustible materials. These problems may be minimized by washing the work area regularly with water and substituting noncombustible materials for combustible materials. For example, sand rather than sawdust should be used for clean-up, diking, etc.

If it possible for solid combustible materials to remain in contact with the hot salt until they are completely oxidized, large volumes of combustion gases can be formed rapidly beneath the salt surface. This could result in violent spattering of hot salt or rupture of equipment.

HITEC itself liberates no toxic vapors, but adequate ventilation should be provided to remove any combustion products that might result from purposeful or accidental contamination of the HITEC. Carbon dioxide and approved drypowder type fire extinguishers can be used satisfactorily to extinguish fires in the vicinity of a salt unit, but vaporizing liquid (carbon tetrachloride), foam, and aqueous types, other than sprinklers or low velocity fog types, should not be used. An adequate supply of clean, dry sand is useful for slagging and diking to confine the spread of escaped molten salt.

If water is purposely or accidently introduced into a unit that contains HITEC the heat input should be kept low until all the water has evaporated; the system should be vented adequately to release the steam that is formed.

HITEC heat transfer salt is a mixture of sodium nitrite, sodium nitrate, and potassium nitrate. Upon contact, these salts are irritating to the eyes and skin. However, the principal health hazards of HITEC are (1) the thermal and oxidizing burn potential of the molten salt when in use, normally at (149-538°C), (300-1000°F); and (2) the toxic effect of the sodium nitrite component if HITEC is swallowed. Trace amounts of sodium nitrite (40% of the HITEC salt) are not considered harmful when taken internally. The oral LD $_{50}$  of sodium nitrite for rats has been reported as 171 mg/kg (Stanford Research Institute, Report No. FDABF-GRAS-084, July 1972). This would be equivalent to 11.5 grams for a 150-pound man. However, because of differences in the metabolism of sodium nitrite by rats and man, as little as one gram may be fatal to humans.

#### 4.2 COLLECTOR SUBSYSTEM DESCRIPTION — CONCENTRATOR ASSEMBLY

The concentrator is defined to include an array of heliostats, the controllers, the control and power distribution cabling, and the functional and hardware interfaces with the plant controller and power supply.

Two concentrator designs are recommended for Engineering Experiment No. 1. The design being developed for the DOE 10 MWe Plant at Barstow, with minor modifications, is recommended for the 3.5-year development program. The MDAC Second Generation Heliostat is recommended for the 4.5 and 6.5 year development programs.

Both of these designs conform to the applicable DOE specifications and the specifications for the Small Power Systems. Hence, the only modifications made to either design are those which provide a short focal length and small image size at the receiver, and those which facilitate low cost transportation, assembly, and installation.

Both heliostats have been defined to the preliminary design level. Modifications necessary to conform to the requirements of a small central receiver system are complete, and the design is defined to a level which will permit evaluations of cost, performance, accuracy, reliability, and maintainability.

## 4.2.1 Design and Performance Characteristics

The concentrator assembly's prime function is to reflect solar radiation onto the receiver assembly which is mounted on a central tower. Concentrator sub-assemblies include: (1) the reflective unit, comprised of mirror modules and support structure; (2) the drive unit, comprised of elevation and azimuth drives; (3) heliostat control and electronics, comprised of power and data interfaces, power and data cabling, control sensors, and neliostat controller; and (4) the foundation and monitoring interface. Also included in the concentrator assembly are the field power and data wiring and field distribution centers, consisting of field controllers, power interfaces with the power generation subsystem and data interfaces with the plant controller. Concentrator field control equipment and interfaces are considered part of this assembly, but are treated in this document under the Plant Control Subsystem.

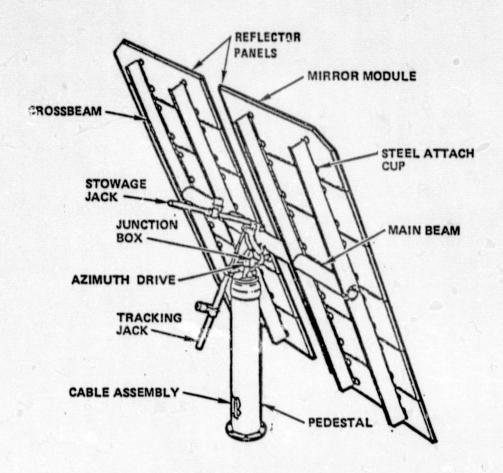
For the 3.5-year program, the baseline heliostats will be based on the heliostats developed by MDAC for the DOE 10 MWe Plant at Barstow, California (DOE Contract EY-76-C-03-1108). For the 4.5 and 6.5 year development programs, the baseline heliostats will be based on the MDAC Second Generation Heliostat design—an improved version of the Barstow heliostat that was developed by MDAC under DOE Contract EG-77-C-03-1605. Overall design and performance requirements for each program startup time are listed in Table 4.2-1. The physical arrangement and boundaries of the array of heliostats have been optimized to concentrate the necessary solar energy on the receiver absorber in the most cost-effective manner. The final heliostat arrangement is sensitive to considerations of heliostat shading, blocking, servicing and geometric parameters yielding an optimal heliostat field layout.

### 4.2.1.1 DOE 10-MWe Heliostat Design Description

The heliostat design selected for the DOE 10 MWe Plant is illustrated in Figure 4.2-1. This design has been modified during the Pilot Plant detailed design phase to reduce its production costs, as noted below. The design, as described, is considered to be appropriate for the 3.5-year program for Engineering Experiment No. 1. A brief description of this design is given below.

Table 4.2-1. Concentrator Assembly Design and Performance Requirements

Item	3.5-Year	4.5-Year	6.5-Year
• Baseline Heliostat Concept	DOE/MDAC 10 MWe Pilot Plant	Second Generation	Second Generation
• Reflective Surface Area	45.3 m <sup>2</sup> (487 ft <sup>2</sup> )	49.0 m <sup>2</sup> (528 ft <sup>2</sup> )	49.0 m <sup>2</sup> (528 ft <sup>2</sup> )
<ul><li>Individual Heliostat Availability</li></ul>	>0.99	>0.99	>0.99
● Tracking Error (1σ)	<3 mr	<3 mr	<3 mr
<ul><li>Number of Helio- stats in Field</li></ul>	217	171	139



45 m<sup>2</sup> REFLECTIVE SURFACE

Figure 4.2-1. Heliostat Assembly

### Mirror Module

The mirror module (Figure 4.2-2) is a bonded sandwich consisting of a second-surface silvered mirror of low iron float glass, a foam core, and a thin, galvanized steel back sheet. Each mirror module is 1.22 m x 3.15 m (48" x 124"). The total reflective surface area is 45.3 m $^2$  (487 ft $^2$ ).

The mirror modules are all curved to a single radius of curvature. The curvature will assure a minimum spillage of reflected light from the receiver for different weather conditions and field locations.

### Support Structure

The support structure is a steel frame which supports and maintains the alignment of the mirror modules. The support structure of the DOE 10 MWe Pilot Plant heliostat design has been modified as illustrated in Figure 4.2-3.

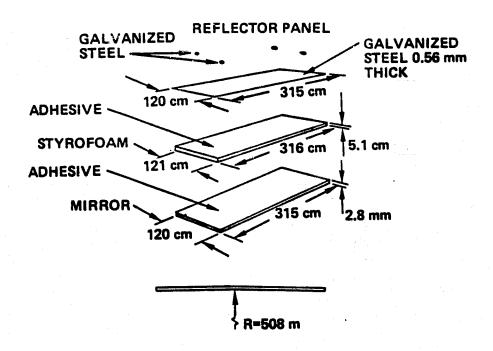


Figure 4.2-2. Mirror Module

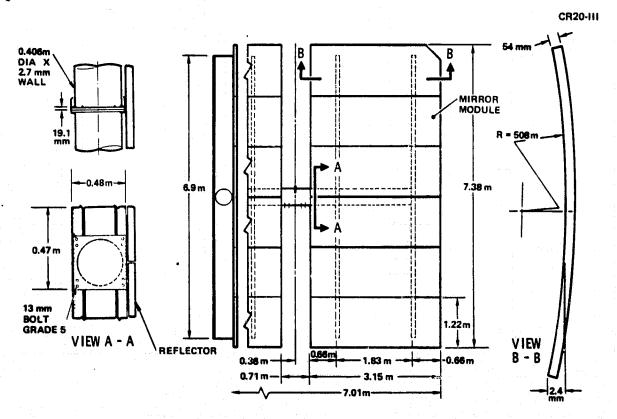


Figure 4.2-3. Design Modifications



The tubular main beam is one piece for the Pilot Plan design. By dividing the beam into three pieces, it is possible to assemble the center section into the drive unit in the factory. Each outboard section is assembled to its channel cross beams, and six mirror modules attached, also in the factory.

The three subassemblies thus formed (drive unit and two reflector panels) are readily transported by common carrier. Each unit may be inspected in the factory, prior to shipment, to minimize corrective labor during checkout in the field. A site assembly facility is not required.

A nominal cant for the mirror modules is preset in the factory for each reflector panel. The angles are chosen such that the outermost row of heliostats is in focus; i.e., that the images from each mirror module on a single heliostat are superimposed on the receiver. Standard spacer kits are provided to adjust the cant angles for the heliostats closer to the receiver. The bolts attaching the mirror modules to the cross beams are loosened, the correct spacers inserted between the attach cups and the cross beams and the bolts retightened. The focus of the entire field is thereby readily achieved without the need to predesignate individual panels for specific spots in the field.

## Drive Unit

Azimuth rotation is obtained by three reduction stages. The first stage is an integral gear head on a 208-VAC, three-phase induction motor; the second stage is a worm/gear pair; and the third is a Harmonic drive unit. The elevation drive employs two machine screw jack actuators coupled with a drag link to provide for the required 180-degree rotation. Each jack is driven by a similar gear motor. The azimuth housing and drag link are castings.

The present Pilot Plant design utilizes limit switches on both linear actuators and on the azimuth drive. Software limit switches will be incorporated into the control algorithms and the electromechanical limit switches will be deleted for the EE No. 1 design.

The preferred drive unit is otherwise the same as that of the Pilot Plant.

### Pedestal/Foundation

A 51-cm (20 in.)-diameter tubular steel pedestal is attached to the drive unit on the upper end and to the foundation on the lower end by bolted flanges. The foundation may be either a precast spread footing or a drilled pier. The anchor bolts are wired to the reinforcement in either case.

### Controls and Electronics

The heliostat employs open-loop control with motor revolution counters for tracking and a nonvolatile memory unit for periodic update/restart capability.

A heliostat controller located on each heliostat retains the motor revolution counts and generates error signals from data transmitted by field controllers. The motor controller section of the heliostat controller then executes the required motor revolutions indicated by the error signal.

The field controller serves as a data interface with the collector controller and calculates time, ephemeris, and gimbal axis position data to transmit to the heliostat controller.

The field electronics (Figure 4.2-4) include power links from the Power Conversion Subsystem and data links from the field controllers to the heliostats. Both hookups are serial. Networks from the distribution panel connect heliostats in a serial or daisy chain arrangement.

4.2.1.2 Second Generation Heliostat Design Description
The heliostat design was developed by MDAC during the DOE prototype Heliostat
Phase I contract (Reference 4-4). This design has been funded for component
design and test by Sandia Laboratories, Livermore under Contract No. 83-0024A,
Second Generation Heliostat Development Program. The design is also proposed
for the Sandia Laboratories Preproduction Heliostat Program.

Minor modifications have been made to the design to ensure its meeting the requirements of small power systems. The design, as described, is considered to be appropriate for both the 4.5-year and 6.5-year programs.

The concentrator assembly is illustrated in Figures 4.2-5 and 4.2-6.



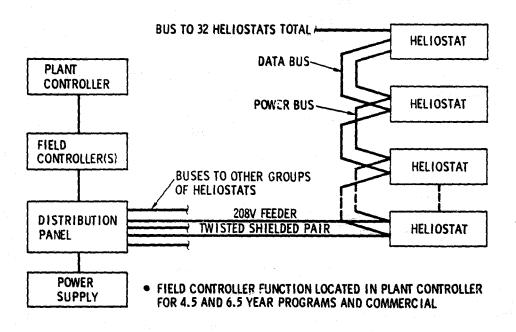


Figure 4.2-4. Concentrator Field Wiring-3.5-Year Program

The heliostat is divided into four subassemblies, based on the physical pieces of hardware delivered to the field. These subassemblies are the reflector panel (one half of the reflective unit), the drive unit (including the pedestal), the foundation, and the heliostat electronics (including controllers and control sensors).

#### Reflector

Each reflector panel is composed of six mirror modules and a support frame. The mirror modules are 1.22 m by 3.35 m (48 by 132 inches) and made of a thin second surface mirror laminated to a float glass back panel. The thickness of the mirror glass is 1.5 mm (0.060 inch). The mirror modules are slightly curved, as before, with the curvature being established during the bonding to the support stringers.

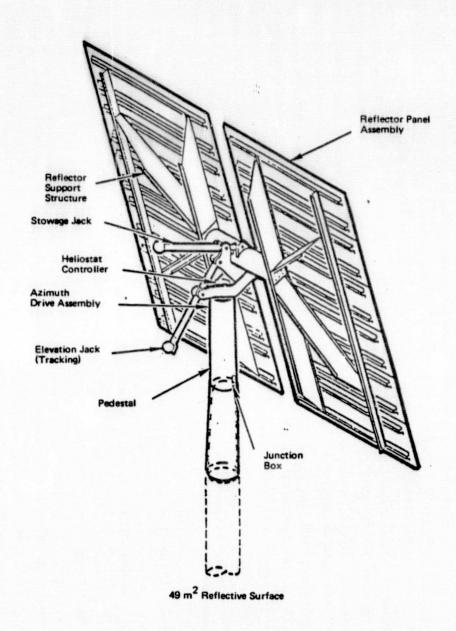


Figure 4.2-5. Second-Generation Heliostat

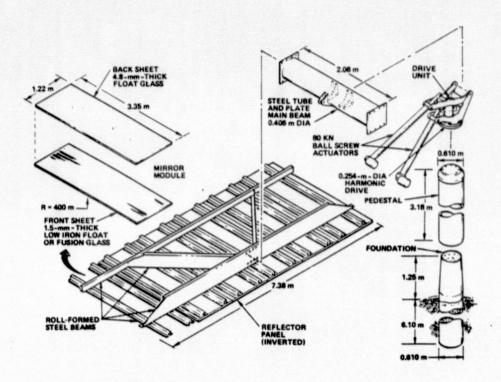


Figure 4.2-6. Second-Generation Heliostat Components

The mirror modules are bonded to stringers which are, in turn, bolted to the cross beams. The outer cross beam is supported by two diagonal beams.

This design achieves a direct production cost reduction compared to the DOE 10-MWe Pilot Plant Design of a bonded foam core sandwich, and provides an indirect cost reduction by use of a thinner glass with higher reflectivity. In addition, the total reflector area is increased commensurate with the drive unit loads.

As with the modified Pilot Plant design, the reflector is made of two fully prealigned panels which are readily transported by common carrier. Adjustment of cant angles is made by preselected spacer kits installed in the field. As before, a site assembly facility is not required.

### Drive Unit

The drive unit is composed of a rotary azimuth drive, a double jack elevation drive, and a pedestal. All drive motors are three-phase, 240-VAC. A 162:1 Heliocon input reducer provides the first azimuth stage reduction. The output is through a 242:1 Harmonic drive reducer. The elevation jacks utilize a Heliocon input gear affixed to the shaft of a ball screw. The two jacks are connected by a drag link. One jack provides tracking motion while the other provides the additional motion required for inverted stowage. The main beam is 40 cm (16-inch) diameter tube flange ends onto which the reflector panels are bolted. The tube has brackets (lugs) which attach to a hinge line on one side and the tracking actuator on the opposite side, providing the final linkage of the elevation drive. The pedestal is a 60-cm (24-inch)-diameter tube with a slight flare on the lower end which matches the tapered top of the foundation and provides a friction joint to the foundation. The top of the pedestal is closed by a dome which bolts to the circular spline of the Harmonic drive. The drive unit is delivered to the field with the heliostat electronics installed and checked out.

This design incorporates a number of improvements, such as a lower-cost, more efficient jack design, lower-cost gears and bearings, and a pedestal design that allows simple field installation. The drive unit with its central main beam also allows a rapid and efficient field installation of the reflector panels in two pieces. The design requires no scheduled maintenance. Removal and replacement of failed parts may be accomplished easily at the component or subassembly level. Repairs are simple, require no special tools, and utilize a piece part remove and replace approach.

### Foundation

The foundation is a drilled pier, 0.6 m (24 in.) in diameter. The pier extends about 1.2 m (4 ft) above grade and 6 m (20 ft) below. A tapered steel shell establishes the mounting surface to the pedestal and serves as a form for the protruding end of the pier. This design speeds field installation, reduces costs, and decreases the amount of steel required for the pedestal by over 272 kg (600 pounds) from the previous bolted pedestal design.

The field electronic arrangement is essentially the same as that described in Figure 4.2-4 for the 3.5-year program. The only significant changes are the voltage increase to 240 VAC.

### Controls and Electronics

The heliostat controller is located in a housing on the top of the drive unit. The controller receives motor count and count rate data from the field controller and responds to requests for data. A microprocessor calculates the motor revolutions required to maintain tracking and activates the motor controllers. The motor controllers switch the motor on and off to produce the required motion. The motor revolution sensors detect motor revolution and direction, and the controller maintains a count of the accumulated revolutions. A nonvolatile memory forms an integral part of the heliostat controller microprocessor and retains motor counts and alignment data in the event of a loss of power. The field wiring terminates at a junction box located on the pedestal. A "tee" junction provides the power to operate the heliostat. All data are routed via a single twisted wire pair to the heliostat controller in the string, decoded by the addressed heliostat and ignored by others unable to match the address code. Acknowledgment of receipt of a message and status are also transmitted.

The design of an integrated pedestal, drive, and electronics unit permits complete assembly and unit testing to be done in the factory, to minimize field labor checkout and costs. The absolute encoders are eliminated, and achieve most of the cost savings projected for the second generation heliostat.

#### 4.2.1.3 Design Selection Rationale

The schedule of Figure 4.2-7 illustrates the rationale for selecting the DOE 10 MWe Plant Heliostat for the 3.5-year program. The need date for heliostats to begin installation is about 1 May 1981 for the 3.5-year program. The pilot plant production will be completed 1 March 1981. The intervening two months will allow more than ample time to make the minor production modifications necessary to produce heliostats for the Small Power System. Hence, heliostat production facility availability is assured.



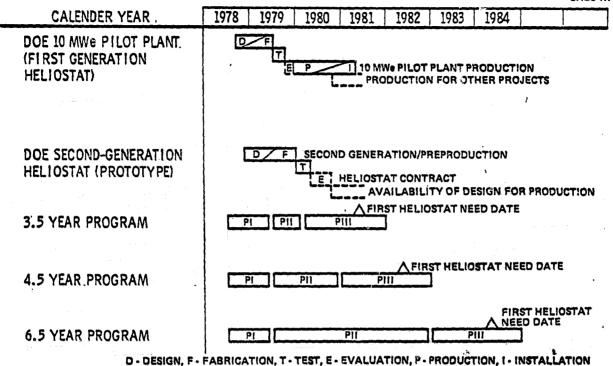


Figure 4.2-7. Heliostat Selection Rationale

The DOE Second Generation Heliostat Program, under the management of Sandia Laboratories, Livermore, is scheduled to produce heliostats which have been tested and evaluated. However, no production program has been scheduled for this design. While it is possible that the design could be available to the 3.5-year program, it appears to be unlikely. Therefore, the first generation, or 10 MWe Pilot Plant Design is chosen.

There are some features of the Second Generation Heliostat concept which may be incorporated into the pilot plant design without incurring any development cost or schedule risk. For example, the control system for the second generation can be implemented with minor hardware changes and might result in a significant cost reduction as compared to the pilot plant control.

The 4.5-year program appears to allow ample time to prepare for production of the second generation heliostat designs. The cost reduction available for this design and the probability that heliostat production will be converted to the second generation approach have lead to its selection as the preferred heliostat design for both the 4.5- and 6.5-year programs. However, the first

generation is available as a backup without significantly affecting the balance of the system.

It should be noted that the components and subassemblies of the two heliostat designs are to a large extent interchangeable. Minor changes in the interfaces will allow the pilot plant design to be incrementally updated to the second generation design. The same philosophy will apply to subsequent design improvements such as those which may emerge from the DOE/Sandia Third Generation Heliostat or New Ideas Heliostat program.

MDAC will maintain a production facility which produces the most cost effective heliostats possible, consistent with production rate and demand forecasts. The production facility will be modified to incorporate design and production method improvements as early as those improvements are cost effective.

## 4.2.2 Operational Characteristics

### 4.2.2.1 Startup Mode

Startup shall begin with a signal from the operator, which initiates a series of prestart checks (heliostat azimuth and elevation positions, power, drive unit enable). The concentrator drive unit then rotates the reflector panels from their stowed position to the proper setting for the beginning of normal operations. The drive unit can position a heliostat from an inverted stowed position to any operational orientation within 15 minutes. The preferred overnight stowage position is vertical. Under normal startup mode, the heliostats will be oriented to their predicted sun acquisition positions at sunrise. The heliostats will acquire the sun and be focussed at two off-target standby points. Sequentially, seven groups of approximately 32 heliostats will ·be focussed on the receiver. Each group of heliostats is directed by one field controller unit. Each group of heliostats can be brought from standby to "ontarget" in 30 seconds. Approximately 10 to 15 seconds delay between groups allows for instrument and control checks. The entire field of heliostats is focused on the receiver in five minutes. The total startup time from sunrise to all heliostats focused on the receiver is 20 minutes. Overall plant operation will begin when the receiver outlet temperature is within 15°C of the



operating requirement. This will occur approximately 10 minutes after all the heliostats are focused on the receiver, and corresponds to a sun elevation angle of approximately 10 degrees above the horizon.

### 4.2.2.2 Normal Operating Mode

Normal operating mode is defined as that period when the heliostats are in the tracking mode and are reflecting solar energy to the receiver. Maximum mirror normal pointing error for each gimbal axis shall be 0.75 mrad ( $1\sigma$ ) whenever the sun is at least 0.26 rad ( $13.6^{\circ}$ ) above the horizon. The reflected beam quality from any heliostat shall be such that a minimum of 90 percent of the reflected energy, if at the maximum target slant range, shall fall within the area defined by the theoretical beam shape plus a 1.4 mrad fringe width. The number of tracking heliostats during normal operation may be varied to vary the flux level on the receiver between zero and the maximum achievable level with step changes no larger than 10 percent of the total collector field output.

#### 4.2.2.3 Intermittent Cloud Coverage Mode

During periods of intermittent cloud coverage, the concentrator assembly shall perform synthetic heliostat track under the control of the plant control subsystem so that normal tracking and solar reflection can be resumed after cloud passage.

#### 4.2.2.4 Normal Shutdown Mode

Normal system shutdown is coordinated through the plant control subsystem. Normal shutdown will be initiated at sunset when the receiver outlet temperature drops below the minimum required value. At the appropriate signal, the heliostats shall be commanded to their standby position. The entire field could respond in 30 seconds, however, due to low solar flux levels, there is no critical time requirement on this repositioning. From the standby mode (two off-target focus points), groups of heliostats will be directed to their stowed position. Beam safety will be maintained and aided by the low sun angle and blockage.

#### 4.2.2.5 Emergency Shutdown Mode

In the event of severe weather conditions or some plant malfunctions, an emergency shutdown shall be executed by command from the plant controller.



The reflector panels shall be rotated to a minimum damage position in a manner compatible with reflected beam safety considerations.

The entire heliostat field is defocused to two focal points located three meters east and west of the receiver. This operation reduces the incident radiation on the receiver surface to less than four percent of its initial value in 30 seconds. The time is determined by the angular travel distance of the closest south facing heliostat to the tower. The time is approximately 30 percent conservative. From the defocused or standby position, the heliostats can be moved to a vertical stowage position in eight minutes while beam safety is maintained. An inverted stowage position would be desirable for severe weather conditions, and an additional six minutes would bring the entire field to inverted stow.

#### 4.2.2.6 Extended Shutdown Mode

For extended shutdown, the heliostats shall be positioned in the inverted position. For special inspection, maintenance, or washing, individual heliostats may be repositioned as required through commands from plant control or by manual operation with local override of the heliostat controller.

4.2.2.7 Typical Concentrator Field Operational Timeline Description (24-Hour Operation for a Typical Equinox Day)

Day to day operation of the heliostats could follow a multitude of scenarios depending on weather conditions, time of year, maintenance conditions, and plant requirements. However, typical operation for an equinox day has been established, and consists of the following events (see Figure 4.2-8).

#### Events

- 1. Night Stowage Position (0000-0145)
  - The desired night stowage position is vertical. This position maximizes average annual reflectivity by providing natural washing from rain and snow, while reducing the overnight dust collection.
- Position 64 Heliostats for Early Morning Washing (0145-0200)
   From the vertical position, 64 heliostats are positioned and aligned for easy access for washing.





Figure 4.2-8. Heliostat Operational Timeline

## 3. Wash Heliostats (0200-0600)

The procedure is to spray on a washing solution, allow it to soak for one minute, and then rinse with deionized water. For Small Power Systems, a specially fitted pickup truck with a two-man crew could wash 64 heliostats in four hours. It would take four days to wash an entire field of 217 heliostats (required for 3.5-year program). Washing is required at intervals ranging from two weeks to three months, with an average of once a month, so 32 manhours a month are required for cleaning maintenance on the average. For a commercial system, automated washing equipment would be developed which would greatly reduce cleaning labor costs by reducing the washing time.

## 4. Sunrise (0600)

For equinox, the sunrise time is 6:00 a.m.

## 5. Position All Heliostats at Standby (0600-0615)

The heliostat field begins to acquire the sun at sunrise and track in the standby mode.

The heliostats can move from any stowage position to any operational position in 15 minutes (rate =  $14^{\circ}$ /min. azimuth and elevation).

# 6. Position All Heliostats on Target (Cold Start) (0615-0620)

The solar flux at 6:15 a.m. is low enough that the entire collector field could be instantly focused on the receiver without causing detrimental thermal stresses. However, for a more controlled cold start, seven groups of approximately 32 heliostats (one field controller per group) are brought on target sequentially. Each group can be focused on the receiver in 30 seconds. Allowing 10 to 15 seconds between groups for instrument and control checks, the cold startup will take five minutes.

# 7. Normal Tracking (0620-TBD)

The heliostats will track the sun in a normal mode. The heliostat azimuth and elevation motion will be directed by the heliostat array controller, heliostat field controller, and individual heliostat controllers.

## 8. Intermittent Clouds (Random)

During normal tracking, clouds can sweep across the field causing a change in receiver solar flux of 100 percent in ten seconds. As long as the receiver outlet temperature remains 15°C above the required minimum temperature, the heliostats will remain focused on the receiver and continue to track. During this time span, the heat transfer fluid flowrate will be lowered. The thermal inertia of fluid in the receiver and the lower isolation provide the desired receiver outlet temperature and normal operation will continue during the short intermittent period.

## 9. Extended Cloud Cover (Random - 1330 For Example)

If cloud cover persists, the receiver outlet temperature will drop below the desired level, and solar energy collection shutdown will be initiated. The heliostat field will simultaneously defocus to the standby positions. This defocus takes approximately 30 seconds. Moving the entire field to standby simultaneously protects the receiver from severe thermal stress should the cloud cover suddenly break. The insulating doors on the receiver may be closed during this time.

## 10. Cloud Clearing - Midday Startup (1440-1500)

In this case, care must be taken not to thermally shock the receiver by suddenly focusing a full mid-day solar flux on it. The seven groups of heliostats will be brought from standby to a target sequentially with two-minute delays between groups to allow for thermal stabilization. The total startup time will be 20 minutes.

# 11. Normal Tracking (1500-1730)

Normal tracking is then resumed, as in Item 7.

# 12. Normal Shutdown (1720-1745)

As the sun begins to set, the receiver outlet temperature will begin to drop. As in the extended cloud cover shutdown, the entire heliostat field will be moved to standby in 30 seconds. From there, each of the seven groups of heliostats will be moved to a vertical stowage position. The focal point for each group will be controlled to maintain safety. Due to the dropping solar flux at sunset and low sun elevation angle, blocking



and shadowing will occur before the focussed beam is low enough to ground level to contact any personnel or facility structures.

## 13. Sunset (1800)

For an equinox day, sunset will occur at 6:00 p.m.

# 14. Night Stowage Position

At 5:45 p.m., all heliostats are in their vertical night stowage position. Wind speed and wind speed rise rates can be automatically monitored during the night. Unacceptable speeds or rise rates would automatically initiate a command to move the heliostats to the inverted stowage position. The entire field can move from the vertical stowage position to the inverted position in 6.5 minutes.

4.3 COLLECTOR SUBSYSTEM DESCRIPTION - RECEIVER ASSEMBLY
The receiver assembly of the collector subsystem is described in this section.

## 4.3.1 Design and Performance Characteristics

Three drawings of the receiver, assembled at the top of the tower, are shown in Figures 4.3-1, 4.3-2, and 4.3-3. The receiver consists of six subassemblies:

- 1. Absorber Unit
- 2. Absorber Support Structure
- 3. Piping, Instrumentation and Supports
- 4. Insulation
- 5. Heaters
- 6. Absorber Door

The following details apply to the 3.5-year program design except as compared (in Table 4.3-1) with the characteristics of the 4.5-year and 6.5-year program configurations. Except for specific dimensions, the following applies to all three configurations.

#### 4.3.1.1 Absorber Unit

Figure 4.3-4 shows the parametric relationships of absorber tube I.D., number of parallel flow paths, pressure drop and fluid velocity. The design point, 4 parallel paths, is selected as the minimum consistent with a pressure drop less than about 7 bars. Figure 4.3-5 shows the design receiver heat flux and temperature profiles. (See Volume V, Section 4.0 for description of receiver thermal and fluid flow analysis.) The absorber is constructed of thin wall seamless tubing, 4.45 cm (1.75 inches) outside diameter and of 0.277 cm (0.109 inch) wall thickness. Four of these tubes in parallel are wound spirally, first in the form of a shallow cone, starting at the largest diameter and working inwardly and toward the apex. At about the half-way point, the angle at the cone apex is changed from that of a shallow cone (150 deg at the apex) to a deep cone (33.4 deg at the apex). The four parallel tubes then spiral inward, forming the surface of a steep cone, to within about 60 cm (2 feet) of the cone apex at which point they are terminated at a conical collecting manifold (Figure 4.3-6) which serves not only to combine the four parallel paths into a single outlet at the apex, but to provide adequate heat absorption and cooling near the apex. The base of the shallow cone



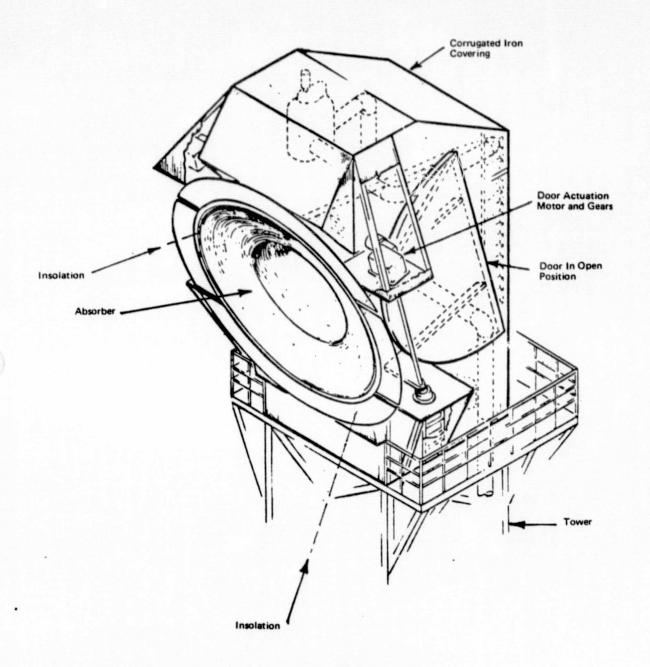


Figure 4.3-1. Isometric Sketch Of Receiver In Place On Top of the Tower

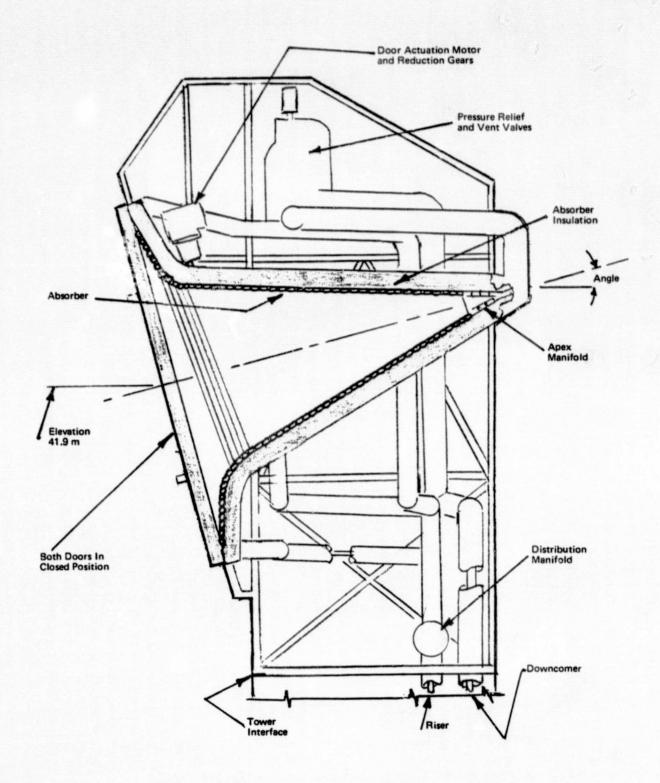
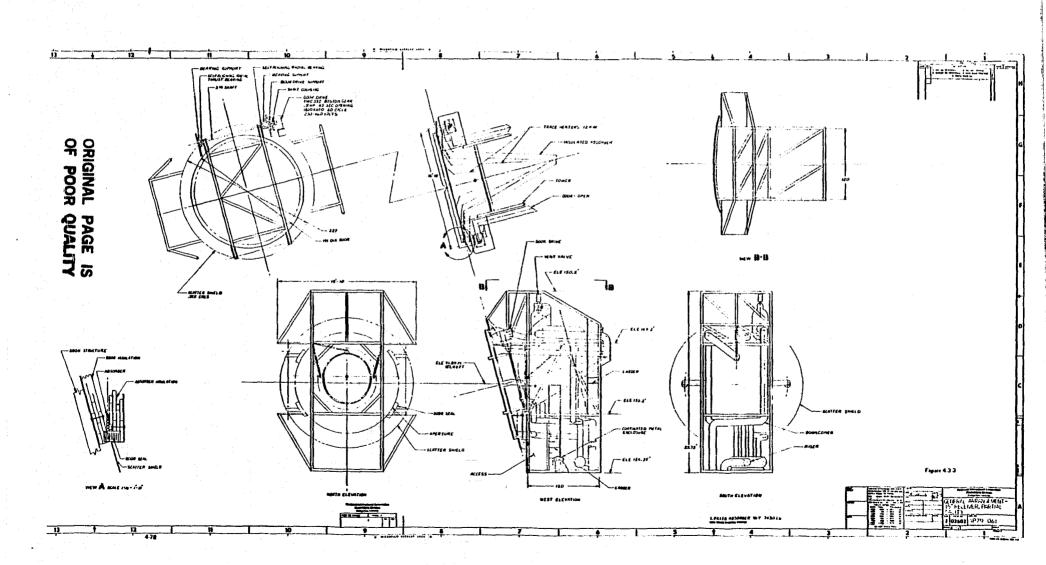


Figure 4.3-2. Partial Cavity Receiver Showing Sectioned Insulated Absorber





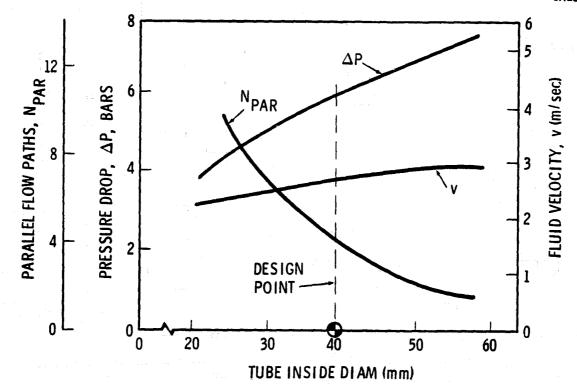


Figure 4.3-4. Absorber Thermal Design—3.5-Year Program

is 4.5 m (14.76 Ft) in diameter and the apex is 4.5 m (14.76 Ft) above the lowest point of the base. The four parallel tubes start at points spaced 90 degrees apart around the outer edge of the base and terminate at the apex manifold at points 90 degrees apart. Thus each of the four tubes has a nearly identical path length and geometrical shape. A distribution manifold, designed to ensure an equal flowrate of coolant to each of the four parallel tubes, is provided ahead of the outer rim. Separate throttling valves and flow meters for each of the four tubes are not provided. The net gain is a simpler, more reliable system.

Before the absorber is accepted, the builder will provide for the measurement of the relative flowrates, using water as a coolant simulant. This will provide proof that each of the four tubes receives an equal share of the coolant flow.

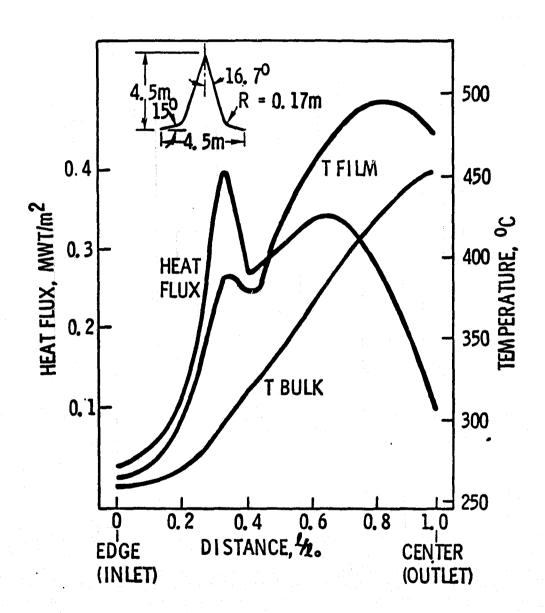


Figure 4.3-5. Heat Flux and Fluid Temperatures



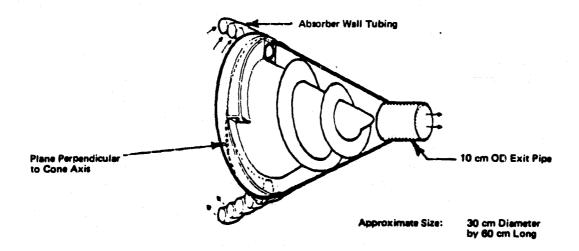


Figure 4.3-6. Exit Manifold at the Absorber Apex

The tubes are held in place by means of a framework as shown in Figure 4.3-7 and Figure 4.3-8. Tabs are welded to the back of every other tube in rows starting at the rim and forming a straight row towards the apex. Each tab has a hole through which a steel rod is threaded. A corresponding set of tabs are welded to a steel beam so placed as to fill the spaces between the tabs on the tubes. These tabs also have holes to permit threading the steel rod alternately through a tab on the beam and then through a tab on the tube and then again through the next one on the beam, etc. In this way the absorber walls are given enough support so that the absorber maintains its shape but allows some tube movement to reduce any concentration of thermally induced stresses during use. This feature, along with the fact that the coils will be tightly wound will give the absorber structure the required rigidity.

#### 4.3.1.2 Absorber Support Structure

A specially constructed steel band is welded along the outside of the absorber at a circumference corresponding to the location of the center of gravity. Rod-end bearings and linkages are then fastened on opposite sides and on top of the absorber to provide the basic support for the absorber in the receiver



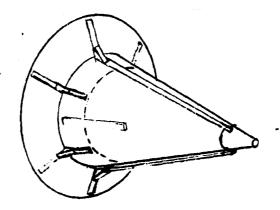


Figure 4.3-7. Absorber Stiffening Framework Showing Six Members at the Large Diameter End,
Four in the Center and Two at the Apex End (Dotted Line is Position of Support Strap)

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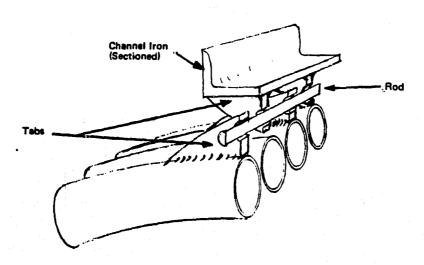


Figure 4.3-8. Cross Section of Absorber Stiffening Frame Detail Showing Fastening Method Permitting Some Freedom of Movement for the Tubes

structure. A similar linkage is provided at the apex to complete the restriction of movement in all six degrees of freedom. This linkage arrangement is shown schematically in Figure 4.3-9. The linkages allow the absorber freedom movement and inducing undesirable thermal stress concentrations.

The cross section of the absorber supporting strap is shown in Figure 4.3-10. It is constructed of flat strap steel which has been cupped so that the two halves reach across three diameters of absorber tubing. As one proceeds around the absorber section through a 90 degree arc, the strap will have moved toward the absorber apex by 1 tube diameter. A transition block is placed midway between the omega joints and permits the strap to move back, away from the apex by 1 tube every 90 degrees, resulting in a supporting strap lying, on the average, exactly perpendicular to the absorber axis. The transition block is so shaped that the two sections coming to it from opposite directions can be welded conveniently in the field. This weld does not involve the tubes and is thus less critical. Transition blocks are placed at the top and the bottom, and on each side of the absorber as viewed when mounted in the receiver. The top one, and those on the sides, simultaneously

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Links With Roderd Bearings
Each End

Structural Support Girders

Absorber (Insulation Not Shown)

Line Through Center of Gravity

Figure 4.3-9. Absorber Support Concept

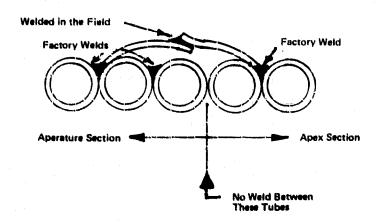


Figure 4.3-10. Concept for Joining the Apex Section To the Aperture Section In the Field

serve as mounting blocks and fastening points for the ends of the support linkages. The omega joints are placed midway between these transition points. The strap has rectangular holes in it at these points to permit the omega joints\* to clearly pass through the strap. The linkages at the transition points are of course not fastened into place until the absorber is actually fitted into the receiver on top of the tower.

This strap thus serves two purposes: (1) it joins the two receiver sections together, and (2) it supports almost the entire absorber weight at the center of gravity.

4.3.1.3 Receiver Piping, Instrumentation, and Supporting Structure Figure 4.3-11 shows the fluid manifold concept. The riser, carrying the colder fluid, comes up the south side of the tower before entering the distribution manifold. Lines carrying the fluid from the manifold to each of the absorber inputs each contain bends to aid in reducing differential expansion forces transmitted to the absorber rim by the piping system.

\*For omega joint description, see Section 5.1.1, Receiver Fabrication.



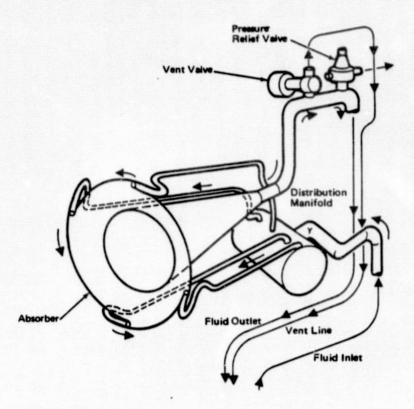


Figure 4.3-11. Manifolding Concept

Tubing having the thinnest practical walls are utilized in order to minimize expansion forces. All joints are welded.

The fluid leaves the absorber at the apex allowing a single larger pipe to be jointed directly to the absorber. This output pipe also makes several turns before attaching to the downcomer on the south side of the tower in order to further isolate the absorber from thermal expansion forces. At the highest point and on the upper crown of the exit pipe are attached two valves: one remotely operated for venting during initial filling of the receiver piping, and the other to function as a pressure relief valve. The exits of these two valves are connected together to a common vent pipe which is in turn strapped inside the insulation on one of the main fluid pipes. The vent line extends to a sump at the bottom of the tower. Thus, the vent line will be kept hot by the fluid and/or tracing present in the main fluid line. (A cold vent line could easily plug with frozen fluid and cause a venting or pressure relief system malfunction.) Obviously, the valves at the top are also enclosed in insulation and provided with trace heating.

Instrumentation will consist only of temperature measuring means at the entrance (rim) and at the exit (apex) of the absorber in the molten salt cooling fluid.

The absorber supporting structure consists of a cold rolled steel framework constructed to form a natural extension of the supporting tower. It is covered on the outside with 1.5 mm thick (16 gauge) corregated galvanized iron forming a weather-proof housing and is provided with access doors and internal ladders to permit reaching all equipment for inspection and maintenance. A steel pan, with turned-up edges, acts also as a floor at the bottom of the structure to prevent salt spillage down the tower should a leak develop. A platform and hand railing (part of the tower) surround the receiver (on the south, east and west sides only) at this same elevation for personnel safety and convenience.

## 4.3.1.4 Insulation and Heat Losses

Solid, hydrous calcium silicate insulation (Johns Manville Thermo-12) is fastened to the outside of the absorber over the trace heater wires, and a thin metal cover to aid in holding the insulation in place is then applied.

The chosen insulation material has a relatively tough, hard composition and is able to withstand repeated wetting without harm. It is lightweight, rigid, easily shaped and installed and is usable on equipment up to 815C (1500F). It has relatively low thermal conductivity for such a rigid material. It is commercially available and is in general use.

#### 4.3.1.5 Heaters

An electrical trace heater with swaged stainless steel sheath and magnesium oxide insulation is electrical impulse welded to the outside of the absorber before insulation is applied. The night time heat loss rate is (initially) at 12 Kw. A trace heater of double this capacity is specified. At a heat load of 160 watts/M the trace heater length is 150 M. The heater is divided into 12 sections, each carrying 9 amps at 220 volts. The heaters are automatically shutoff when the system reaches its specified temperature to prolong the life of the heater wire. The thermal inertia of the absorber when filled



with salt is sufficient to maintain the subsystem well above the solidification temperature with the door closed during the hours from sundown to sunup, based upon an initial cooldown rate of 9.4C/Hr (17F/Hr) for the 12 Kw heat leakage rate typical of the hot absorber when the doors are closed at the end of the day.

#### 4.3.1.6 Absorber Doors

The receiver has doors, Figure 4.3-1, which swing sideways and back during periods of insolation and which cover the face of the absorber during standby operation. Each door consists of a steel framework with insulation identical to that which is on the absorber mounted on its inside face. The edges are beveled to match the beveled edge on the absorber insulation to aid in sealing the trapped hot air when the doors are closed.

Each door is pivoted on a shaft held in place by two bearings, one pair on each side of the tower. Actuation is by means of a reversible electric motor and gear reduction. Each motor and gear reduction are sized to ensure that the doors can be closed against the pressure created by the specified wind conditions. If feasible, hand crank closure or opening will be provided, to be restricted for use only under emergency conditions.

Receiver design details for the 3.5-, 4.5-, and 6.5-year programs are summarized in Table 4.3-1.



Table 4.3-1. Receiver Characteristics

Program Duration	<b>3-1/2</b> Year	4-1/2 Year	6-1/2 Year	
Peak Power, Mwt Absorbed	7.08	6.05	4.87	
(or Fluid Heat Load)				
Fluid (Type)	HITEC	HITEC	HTS	
Wt. Flow Rate, Kg/Hr (Lb/Hr)	<b>84,000</b> (184800)	62,800 (138160)	44,900 (98780	
Vol. Flow Rate, @ 427 C (800 F),	13.2 (209)	9.84 (156)	6.84 (108)	
L/sec (Gal/Min)				
Inlet Temp., C (F)	<b>260</b> (500)	288 (550)	288 (550)	
Outlet Temp, C (F)	<b>454 (</b> 850)	510 (950)	838 (1000)	
Pressure drop, Bars (Lb/In <sup>2</sup> )	<b>5.86</b> (85)	3.0 (44)	3.6 (52)	
Pumping Power, Kw Hyd.	7.7	4.0	2.4	
Maximum Velocity M/Sec (Ft/Sec)	2.77 (9.1)	2.13 (7.0)	2.6 (7.1)	
Absorber	• • •		• •	
Aperture Size, m Dia. x m Deep	4.5 x 4.5	4.28 x 4.28	$4.0 \times 4.0$	
(Ft x Ft)	$(14.76 \times 14.76)$	$(14.1 \times 14.1)$	$(13.1 \times 13.1)$	
Peak Heat Flux Kw/M <sup>2</sup> (BTU/Hr Ft <sup>2</sup> )	418 (132380)	393 (124604)	399 (126550)	
Thermal Efficiency	0.89`	0.89	0.89	
Coating Absorptivity	0.95	0.95	0.95	
Weight Kg (1bs)	1880 (4134)	1700 (3750)	1290 (2843)	
Temperatures	2000 (1201)	2,55 (5,55)		
Max. Outside Tube				
Wall Temperature, C (F)	519 (966)	569 (1056)	603 (1117)	
Max. Inside Tube	(200,	(2000)		
Wall Temperature, C (F)	478 (892)	534 (993)	577 (1071)	
Max. Temperature Difference,	110 (032)	00. (330)	077 (2072)	
Across Tube Wall, C (F)	40 (72)	37 (66)	33 (59)	
Across Tube From Front to Back, C (F)	123 (221)	71 (127)	119 (214)	
Tubing	120 (221)	/2 (42/)	113 (117)	
Outside Diameter, Cm (in.)	4.455 (1.75)	4.455 (1.75)	3.81 (1.5)	
Wall Thickness, Cm (in.)	0.277 (0.109)	0.277 (0.109)	0.241 (0.095)	
Material	316 CRES	316 CRES	INCO-800	
Number of Parallel Paths	4	4	4	

#### 4.4 TOWER SUBSYSTEM CHARACTERISTICS

The tower design characteristics presented in this section represent a preliminary description of the tower and the necessary ancillary equipment.

The tower is a guyed-steel structure which is designed to support the weight of the receiver and ancillary equipment and is capable of surviving wind and seismically induced overturning moments. The principal elements of the tower include:

- Structure.
- Guy wires.
- Foundation.
- Work platforms.
- Pipe Supports.
- Acess ladder and service elevator.
- Plant services (water, GN<sub>2</sub>, electric power, pneumatic lines, lightning, lightning protection, etc.).
  - Instrumentation.

The preliminary tower design is shown on a conceptual basis in Figure 4.4-1.

The tower structure is 39 m (128 ft) high and is constructed of structural steel angles (15 x 15 cm). The vertical members are located on a square pattern 3.05 m on a side and serve as the four attachment points for the receiver. The tower contains 11,800 Kg of structural steel (A36). Special provisions are included for the attachment of pipes and cables, the caged ladder, and the service elevator. The structural steel is painted to prevent corrosion.

The guy wires extend in a diagonal direction outward from the tower and are at a 45° angle relative to vertical. The guys are made of galvanized bridge cable and are attached to the tower one tower-section below the receiver. The cable is 2.54 cm in diameter and is tensioned to allow less than a 15 cm receiver deflection at a reference wind speed of 16.1 m/s (at 10 m vertical elevation).

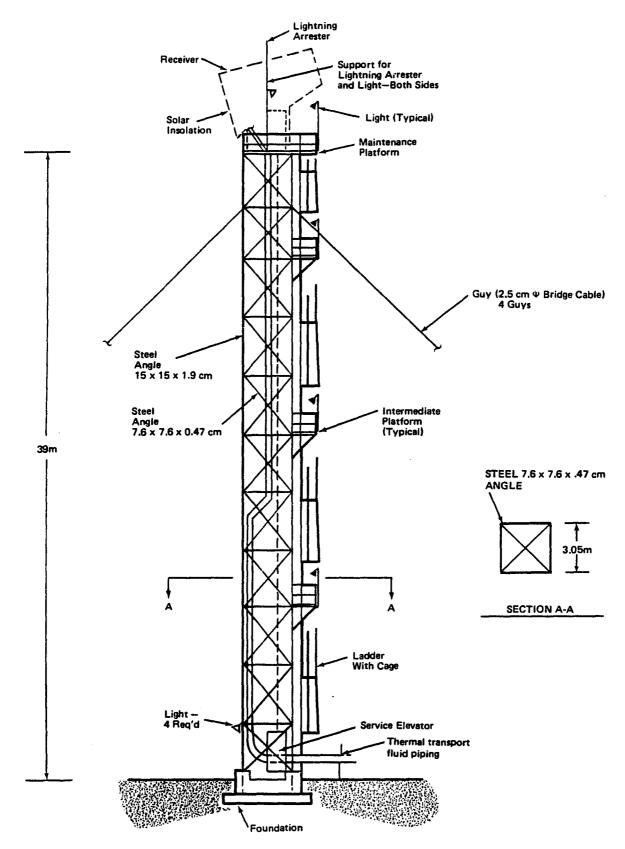


Figure 4.4-1. Guyed Receiver Tower

MCDONNELL DOUGLAS

The tower foundation is of a mat design made up of reinforced concrete. The mat is square (6.1  $\times$  6.1 m) and 0.61 m thick. The mat contains 28 m<sup>3</sup> of concrete. Each dead man anchor for the guy wires is a 1.5  $\times$  1.5  $\times$  2.1 m concrete block which is buried 1.5 m below grade.

Details of the work platform located at the top of the tower are shown in Figure 4.4-2. The platform is designed to give access to the back and sides of the receiver. It utilizes steel gratings and standard railings per OSHA standards. Access to the platform is either by the caged ladder or service elevator. Safety gates surround these access openings. At points along the caged ladder route, intermediate platforms are located which can serve both as rest and local work areas. These platforms are also made of steel gratings and utilizes standard safety railings.

The pipes are restrained and supported by standard counter-weight pipe supports which allow the pipes to expand downward from the receiver interface plane at the 39 m elevation. The maximum vertical pipe travel at the bottom of the tower is 22.7 cm which will be accommodated by the pipe support.

CR20-III

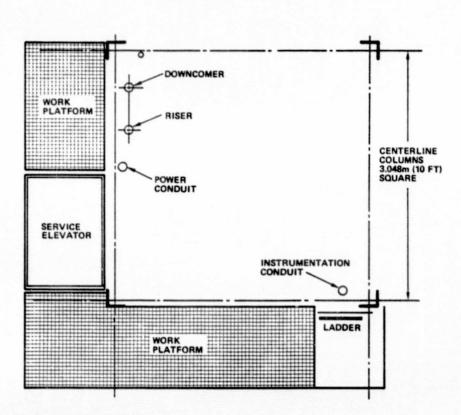
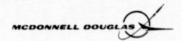


Figure 4.4-2. Typical Platform Arrangement



Sufficient clearance will be maintained between the final bend and the ground or ground-mounted structures to allow for this pipe growth.

The access ladder will provide access from the ground to the tower top work platform. The design will be developed in accordance with OSHA requirements and will include the necessary intermediate rest platforms.

The service elevator will be mounted on the side of the tower as shown in Figure 4.4-2 and will provide direct access to the work platform. It will be designed to accommodate two people plus lightweight tools. The elevator will be capable of stopping at intermediate locations for maintenance and repair as required. At each location, adequate safety provisions will be made for the maintenance personnel.

Plant service lines will be routed up the tower to provide water, GN<sub>2</sub>, electric power, and compressed air to the tower top work platform as well as any of the intermediate work levels on an as required basis. The electrical power lines will also service trace heaters and the tower lights which are placed as indicated in Figure 4.4-1. In addition, a high-intensity white light will be mounted at the highest point of the receiver-tower structure along with necessary aircraft warning lights in compliance with FAA regulations. Lightning arresters will be located to protect the highest portion of the receiver-tower structure while provisions will be included in the tower design to accompdate the arrester grounding cable.

Instrumentation lines required for the operation, control, and/or monitoring of the receiver and riser/downcomer will be mounted to the tower. The location of these wires and the shielding and protection will be selected to isolate these lines from both environmental and electromagnetic interference.

#### 4.5 ENERGY STORAGE SUBSYSTEM CHARACTERISTICS

## 4.5.1 Design and Performance Characteristics

The thermal storage subsystem, as indicated in Figure 4.5-1 and 4.5-2, consists of the following components:

- Storage Tank(s) and Media
- 2. Insulation
- Immersion Heater(s)
- 4. Gaseous Nitrogen Supply

## 4.5.1.1 Storage Tank(s) and Media

## 3.5- and/or 4.5-Year Programs

Both tanks are horizontally mounted, cylindrical tanks with dished heads. The tank diameters were set at 3.6m to permit transportation to the site. The tanks are used to contain molten Hitec and each contains a submerged pump and immersion heater. The high temperature vessel (hot tank) is used to accumulate Hitec flowing from the receiver until required by the power conversion subsystem

CR20-III Relief Rupture Submerged Pump From To Steem Receiver Generator Hot Tank Pressure Equalization Drain Line GN<sub>2</sub> Fill From Steem Generator 4 1/2 yr 3 1/2 yr Cold 288°C 260°C Tank 510°C 454<sup>0</sup>C

Figure 4.5.1. Hitec/Two-Tank Thermal Storage Subsystem



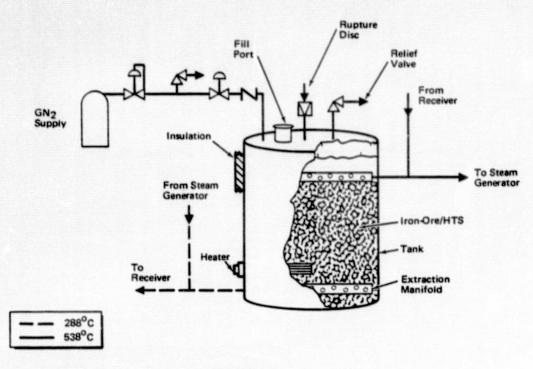


Figure 4.5-2. Dual Media Thermocline Energy Storage Subsystem

and is made of stainless steel. After flowing through the steam generator, Hitec is pumped to the low temperature vessel (cold tank) to be stored for return to the receiver. This tank is made of carbon steel. Each tank is equipped with a relief valve and a safety rupture disc as well as thermocouple wells, liquid level indicators, and a pressure transducer.

#### 6.5-Year Program

A single, vertically mounted, stainless steel tank is used to contain molten HTS and iron ore. The iron ore will have a void volume of approximately 40 percent which is filled with molten HTS. Colder HTS will be drawn from a manifold located at the tank bottom, pumped through the receiver and returned to the manifold location in the top of the tank. Hotter HTS will be extracted from the top of the tank, pumped through the steam generator, and returned to the tank bottom manifold. The quantity of storage media is oversized by 10 percent to allow for the thickness of the thermocline.

An additional 6 percent is allowed for excess fluid and manifolds, and 3 percent for ullage space.

The diameter of the tank is also limited to 3.6m and the length/diameter ratio will be greater than 1.5. Safety features include a pressure relief valve and rupture disk. Thermocouple wells, liquid level indicators, and a pressure transducer will be used to monitor tank conditions.

A summary of tank specifications is given in Table 4.5-1 to 4.5-3 and characteristics of Hitec and HTS described in Volume V. Section 10.1.

#### 4.5.1.2 Insulation

All tanks are covered with insulation and an aluminum weather cover. The insulation thickness was optimized for minimum energy cost and is given in Tables 4.5-1 to 4.5-3 for the various tanks. For tanks operating above 454°C, high temperature mineral wool will be used. For low-temperature tanks, less-expensive fiberglass will be used.

#### 4.5.1.3 Immersion Heater

A 100-kW immersion heater will be utilized in each tank to melt the salt during initial salt filling operations or following extended shutdown periods when the salt was allowed to freeze. The heaters will also be used to maintain salt in the tank at operating temperature during long standby modes. Heat paths to upper fluid surfaces will be provided to prevent tank rupture during melting.

#### 4.5.1.4 Gaseous Nitrogen Supply

Gaseous nitrogen is utilized to provide an inert blanket to prevent oxidation of sodium nitrate, the formation of sodium hydroxide from atmospheric moisture and the formation of sodium carbonate from the absorption of carbon dioxide. These reactions would lead to increased melting points, corrosion, and precipitate formation.

As shown in Figure 4.5.3, the hot and cold tanks are interconnected with 5 cm piping so that nitrogen flows to the tank being emptied from the other tank.

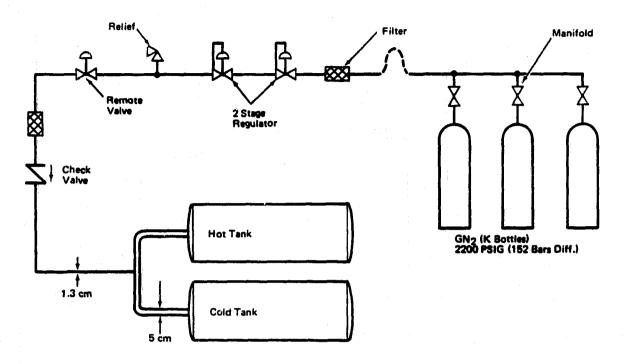


Figure 4.5.3. Gaseous Nitrogen Cover Gas System

Nitrogen pressure will be regulated automatically to maintain a minimum pressure of 5 psig (0.34 bars differential) in the tanks.

As nitrogen fills the hot tank and warms up, the pressure will increase to approximately 0.69 bars (10 psig differential). The tanks will have a capacity of 62.3 and 85 M<sup>3</sup> (standard conditions), respectively, for the 3.5-year and 4.5-year programs.

The design and performance characteristics of the principal components of the energy storage subsystem are shown in Tables 4.5-1 to 4.5-3.

#### 4.5.1.5 Interfaces

## 3.5-Year and 4.5-Year Programs

The principal interfaces will include mounting flanges on each tank for the submerged pump, immersion heater, and salt fill port. Nozzles on the upper shell will be provided for the fluid return line, nitrogen line, relief valve, and rupture disc. Provision for the drain valve, thermowells, and level sensors will be included.



Table 4.5-1. Thermal Storage Design Description, 3-1/2 Year Program

Conf	igur	at	ion

One cylindrical hot tank, one cylindrical cold tank

Horizontal axis, mounted on low density concrete or dry soil of adequate bearing strength

Tank Dimensions

Cold Tank

Hot Tank

Inside Diameter

3.66m

3.66m

Length

10.43m

11.27m

Thermal Performance

Storage Capacity

17.1 MWHt

Hours at Rated Power

4.1 HR

Storage Temperatures

Hot Tank (Nominal)

454°C 260°C

Cold Tank (Nominal)

Heat Losses (% of Extractable)

3.7%

Liquid Storage Medium

Hitec (53%  $KNO_3$ , 40%  $NaNO_2$ , 7%  $NaNO_3$ )

Minimum Requirement Buffer Quantity

194,094 KG

8547 KG

Tank Structure

Cold Tank

Hot Tank

**Fabrication** 

Shop

Shop

Material

**AISI C1015** Carbon Steel 316

Plate Thickness

11.1 mm

Stainless Steel

8.1 mm

High Temperature Fiberglass Insulation with Aluminum

20.3 cm

Weather Cover

Immersion Heater

27.9 cm

High Temperature Mineral Fiber (Block) Insulation

100 KW

100 KW

Gaseous Nitrogen System

Delivery Pressure (Differential)

0.34 Bars

## Configuration

One cylindrical hot tank, one cylindrical cold tank

Horizontal axis, mounted on low density concrete or dry soil of adequate bearing strength

Tank	Dimen	sions
· WILL	D IIIICI	3 10113

Cold Tank

Hot Tank

Inside Diameter Height (Minimum)

3.66m 8.05m 3.66m 8.81m

## Thermal Performance

Storage Capacity

14.9 MWHt

Hours at Rated Power

4.2 HR

Storage Temperatures

Hot Tank (Nominal) Cold Tank (Nominal) 510°C

288°C

Heat Losses (% of Extractable)

3.5%

# Liquid Storage Medium

Hitec (53% KNO<sub>3</sub>, 40% NaNO<sub>2</sub>, 7% NaNO<sub>3</sub>)

Minimum Requirement Buffer Quantity

148,586 KG 6315 KG

# Tank Structure

Fabrication Material

Shop **AISI C1015** 

Cold Tank

Hot Tank

Shop 316

Carbon Steel 11.1 mm

Stainless Steel

Plate Thickness

8.1 mm

High Temperature Fiberglass Insulation with Aluminum

22.9 cm

Weather Cover

High Temperature Mineral Fiber (Block) Insulation

30.5 cm

Immersion Heater

100 KW

100 KW

# Gaseous Nitrogen System

Delivery Pressure (Differential)

0.34 Bars

# Configuration

concrete.

One cylindrical tank, vertical axis, mounted of	on low density o
Tank Dimensions	
Inside diameter	3,64 m
Height	5.75 m
Packed Bed Height	5.04 m
Fluid Surface Height (538°C)	5.59 m
Top Manifold Height	5.07 m
Bottom Manifold Height	0.158 m
Thermal Performance	
Storage Capacity	12.5 MWHt
Hours at Rated Power	4.4 HR
Storage Temperatures	
Maximum Minimum	538°C 288°C
Heat Losses (% of Extractable)	2.3%
Solid Storage Medium	
Iron Ore Pellets (63% Fe)	
Total Mass	174,660 KG
Void Fraction	0.4
Liquid Storage Medium	
Heat Transfer Salt (53% KNO <sub>3</sub> , 47% NaNO <sub>3</sub> )	
Total Mass	43,285 KG
Tank Structural Details	
Fabricated of 316 Stainless	
Plate Thickness	8.1 mm
Roof and sides covered with high temperature mineral fiber (block) insulation and aluminum weather cover	30.5
Immersion Heater	100 KW
Gaseous Nitrogen Supply	
Delivery Pressure (Differential)	0.17 Bars

Relief Pressure

0.34 Bars

## 6.5-Year Program

The principal interfaces will include mounting flanges for the upper and lower HTS manifolds, immersion heater, and salt fill port. Nozzles on the upper shell will be provided for the nitrogen line, relief valve and rupture disc. Thermowells and level sensors will be located on the shell.

## 4.5.2 Operational Characteristics

The operational characteristics of the Energy Storage Subsystem are intimately related to the operational characteristics of the Energy Transport Subsystem. Accordingly, rather than duplicating the descriptions, the reader is referred to the discussion in Section 4.6.2.

## 4.6 ENERGY TRANSPORT SUBSYSTEM CHARACTERISTICS

## 4.6.1 Design and Performance Characteristics

## 3.5-Year and 4.5-Year Programs

The energy transport subsystem consists of a receiver loop, a steam generation loop, and an intertank transfer subsystem as shown on Figure 4.6-1. In the receiver loop Hitec is drawn from thermal storage, pumped through the solar receiver, and returned to thermal storage. In the steam generation loop, Hitec is drawn from thermal storage, pumped through the steam generator, and returned to thermal storage in the cold tank. The inter-tank fluid transfer subsystem uses additional piping and valves in conjunction with the same pumps to transfer Hitec between the two tanks as required by operational circumstances.

## 6.5-Year Program

As shown on Figure 4.6-2, the energy transport subsystem consists of a receiver loop and a steam generation loop. In the receiver loop, HTS is drawn from the dual media thermal storage tank, pumped through the solar

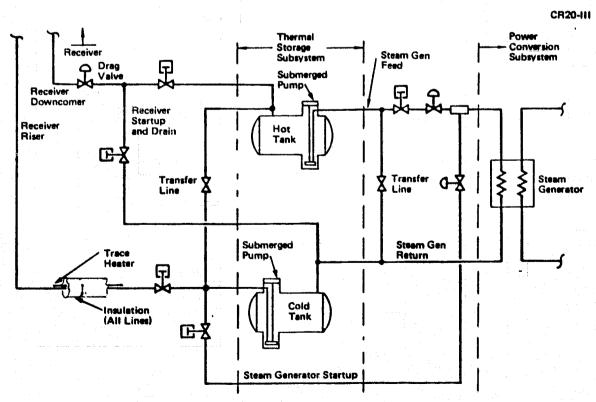


Figure 4.6-1. Two-Tank Energy Transport Configuration

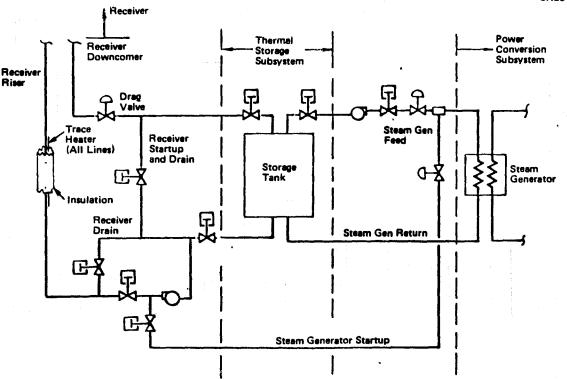


Figure 4.6-2. Dual Media Thermocline Energy Transport Configuration

receiver, and returned to thermal storage. In the steam generation loop, the HTS is drawn from the dual media thermal storage tank, pumped through the steam generator, and returned to thermal storage.

All systems provide lines to facilitate warmup operations during startup and draining lines following shutdown.

The energy transport subsystem consists of the following major components:

- 1. Molten salt pumps.
- 2. Pipe lines and insulation.
- 3. Valves and actuators.
- 4. Trace heaters.

#### 4.6.1.1 Molten Salt Pumps

#### 3.5-Year and 4.5-Year Programs

Both pumps are centrifugal, vertical shaft, designs with sleeve bearings in the fluid. The cold tank pump is a carbon steel, four stage diffuser type



with a ni-resist shaft and metallic stuffing box which would require no lubrication. The pump will have a ball thrust bearing above the cover plate and will be connected directly to the driver by a flexible coupling.

The pump located in the hot tank will be a single stage design constructed of stainless steel. All pumps will operate at 1800 RPM.

## 6.5-Year Program

Because of the difficulty involved with using submerged pumps with a vertical tank, those for the 6.5 year program are specified as horizontal, centrifugal, in-line designs. The low temperature, high head pump is available but the steam generator pump operating at 538°C will require qualification of stuffing-box seals which will probably be a graphoil ribbon.

Specifications for all system pumps are given in Tables 4.6-2 to 4.6-4.

## 4.6.1.2 Pipelines and Insulation

All pipelines are standard schedule 40 pipes and are butt welded where possible. Ring joint flanges are used otherwise. The system layout is shown in Figure 4.6-3 for the 3.5/4.5 year program and lines are designated by numbers which refer to specifications given in Table 4.6-1. All lines and valves are insulated with 10.2 cm of calcium silicate and protected with an aluminum weather cover. Joints are sealed with insulating cement. The system layout for the 6.5 year program is essentially the same except that a vertical storage tank replaces the two horizontal storage tanks. Pipe hangers and supports are not specified.

#### 4.6.1.3 Valves and Actuators

The type and location of all valves are indicated in Figures 4.6-1 and 4.6-2.

These are all standard type valves and will be compatible with the operating temperature and size of the line in which they are located. All valves are rated at 21 bars and contain high temperature asbestos gaskets. Remote control valves will use pneumatic actuators.



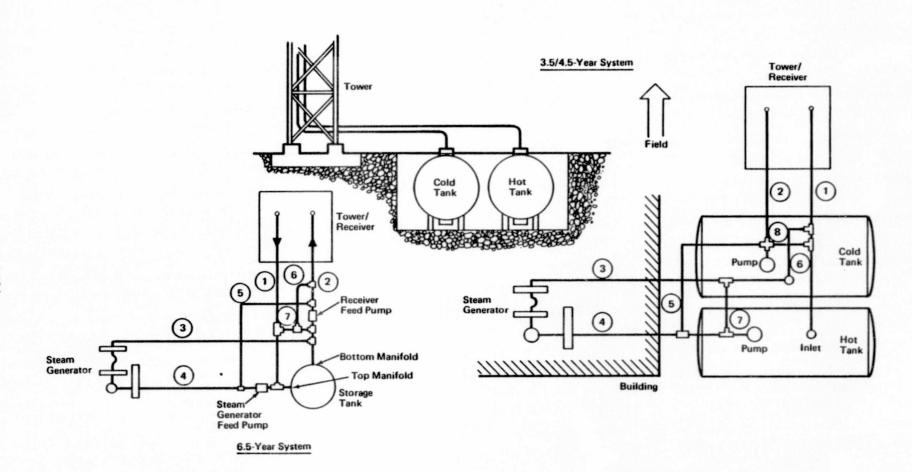


Figure 4.6-3. Energy Transport System Layout

The control valve located at the base of the receiver downcomer is a low noise type valve designed to dissipate the tower hydrostatic head. Since the receiver feed utilizes a constant speed drive, the developed head will increase while the system frictional losses decrease as the flow rate decreases. The design pressure drop requirements between maximum and minimum flow are shown below, along with the valve flow coefficient.

	3.5 Yr	4.5 Yr	6.5 Yr	
Pressure Drop, Bars				
Maximum Flow	4.7	5.3	4.4	
Minimum Flow	16.9	12.6	11.6	
Flow Coefficient	and the second		ŧ.	
Maximum Flow	31.5	22.1	17.2	
Minimum Flow	1.7	1.4	1.1	

#### 4.5.1.4 Trace Heaters

Trace heaters will be attached to all lines and valves and controlled such that the temperature of the heat transfer salt is maintained above the freezing point. All are electrical heating cables insulated with magnesium oxide and covered with a stainles steel sheath for high temperature operation. The control temperatures are 171°C for the 3.5-year and 4.5-year programs, and 260°C for the 6.5-year programs. The heaters will be attached to the lines with stainless bands and heat transfer cement prior to application of the insulation. Separate circuits are provided for each line listed in Table 4.6-1.

The design and performance characteristics of the principal components of the energy transport subsystem are shown in Tables 4.6-2 to 4.6-4.

#### 4.6.1.5 Interfaces

# 3.5-Year and 4.5-Year Programs

The principal interfaces will include Hitec inlet and outlet lines from each storage tank, the Hitec inlet and outlet of the solar receiver, and the Hitec inlet and outlet of the steam generator.

Table 4.6-1. Piping Specifications

Pipe* Line	Те	mperatu (°C)	ire		Size (cm)		Schedule	Material
	3.5	4.5	6.5	3.5	4.5	6.5	i i	
1	454	510	538	7.6	7.6	6.4	40	Stainless 316
2	260	288	288	7.6	7.6	6.4	40	Carbon Steel
3	260	288	288	6.4	6.4	5.1	40	Carbon Steel
4	454	510	538	6.4	6.4	5.1	40	Stainless 316
5	260	288	288	6.4	6.4	5.1	<b>4</b> 0	Carbon Steel
6	454	510	538	7.6	7.6	6.4	40	Stainless 316
7	454	510	538	6.4	6.4	6.4	40	Stainless 316
8	260	288		7.6	7.6		40	Carbon Steel

<sup>\*</sup>Numbers refer to pipe lines shown in Figure 4.6-3.

## 6.5-Year Program

The principal interfaces will include the HTS inlet and outlet from the storage tank, the solar receiver HTS inlet and outlet, and the steam generator HTS inlet and outlet.

# 4.6.2 Operational Characteristics

Operational timelines were given in Section 4.1. The fluid routing corresponding to the major modes are described here.

## 4.6.2.1 Startup Mode

Operations will be described separately for the 2-tank and single tank configurations.

# 3.5-Year and 4.5-Year Programs

The daily startup mode is shown on Figure 4.6-4. In this mode, the Hitec will be drawn from the cold tank, pumped through the receiver, and returned to the cold tank until the fluid leaving the receiver reaches the system operating temperature. Fluid is controlled by control valve CV-1 with remote valves RV-2 and RV-1 open and closed, respectively.

Table 4.6-2. Energy Transport Subsystem Design Description, 3-1/2 Year Program

Component		Description
Receiver feed pump	Type Head rise Design flow rate Drive Power Material	Centrifugal, submerged bearings 16 bar 83,950 kg/hr 50 Kw Carbon steel
Steam generator feed pump	Type Head rise Design flow rate Drive power Material	Centrifugal, submerged bearings 4.4 bar 50,280 kg/hr 7 Kw Stainless 316
Valve, remote (7)	Type Size	Shutoff, flow control 7.6 cm - receiver circuit 6.4 cm - steam generator circuit
	Pressure rating (All valves)	Circuit
Valve, drag (1)	Type Size Pressure drop Material	Velocity control 7.6 cm 4.7-16.9 bars Stainless steel
Valve, manual (2)	Type Size	Shutoff 7.6/6.4 cm
Piping	Size	7.6 cm - receiver circuit 6.4 cm - steam generator circuit
	Schedule Material	40 Carbon steel/stainless 316
Insulation	Thickness Material	10 cm Calcium Silicate
Trace heating	Watts/meter	57 - receiver loop 50 - steam generator loop

Valves and lines operating above  $430^{\circ}\text{C}$  are stainless 316, otherwise carbon steel is specified.

Table 4.6-3. Energy Transport Subsystem Design Description, 4-1/2 Year Program

Component		Description
Receiver feed pump	Type Head rise Design flow rate Drive power Material	Centrifugal, submerged bearings 12.7 bars 62,770 Kg/Hr 30 KW Carbon steel
Steam generator feed pump	Type Head rise Design flow rate Drive power Material	Centrifugal, submerged bearings 3.0 bars 37,150 Kg/hr 4 Kw Stainless 316
Valve, remote (7)	Type Size	Shutoff, flow control 7.6 cm - receiver circuit 6.4 cm - steam generator circuit
	Pressure rating	21 bars
	Material	
Valve, drag (1)	Type Size Pressure drop Material	Velocity control 7.6 cm 5.3 - 12.6 bars Stainless steel
Valve, manual (2)	Type Size	Shut off 7.6/6.4 cm
Piping	Size	7.6 cm - Receiver circuit 6.4 cm - Steam generator circuit
	Schedule Material	40 Carbon steel/stainless
Insulation	Thickness Material	10 cm calcium silicate
Trade heating	Watts/meter	57 - receiver loop 50 steam generator loop

<sup>\*</sup>Valves and lines operating above 430°C are stainless 316, otherwise carbon steel is specified

Table 4.6-4. Energy Transport Subsystem Design Description, 6-1/2 Year Program

Component		Descrip <b>tion</b>
Receiver feed pump	Type Head rise Design flow rate Drive power Material	Centrifugal, in line 12.5 bars 44,920 kg/hr 16 kw Carbon steel
Steam generator feed pump	Type Head rise Design flow rate Material Drive power	Centrifugal, in line 2.1 bar 26,100 kg/hr Stainless 316 2 kw
Valve, remote (10)	Type Size	Shutoff, flow control 6.4 cm - receiver circuit
	Pressure rating (all valves)	5.1 cm - steam generator circuit 21 bar
Valve, drag (1)	Type Size Pressure drop Material	Velocity control 6.4 cm 4.4 - 11.6 bars Stainless steel
Piping	Size	6.4 cm - receiver circuit 5.1 cm - steam generator circuit
Insulation	Thickness Material	10 cm Calcium Silicate
Trace heating	Watts/meter	96 - receiver loop 87 - steam generator loop

Valves and lines operating above 430°C are stainless 316, otherwise carbon steel is specified.

The cold tank and hot tank will both supply Hitec to the steam generator during the startup to warm the equipment and preclude the problem of thermal shock which would be associated with startup using fluid at the full operating temperature. Valves RV-3 and RV-5 are opened and flow is metered by control valves CV-2 and CV-3.

## 6.5-Year Program

In the daily startup mode, the system will be configured as shown on Figure 4.6-5. In this configuration, the HTS will be drawn from the bottom of



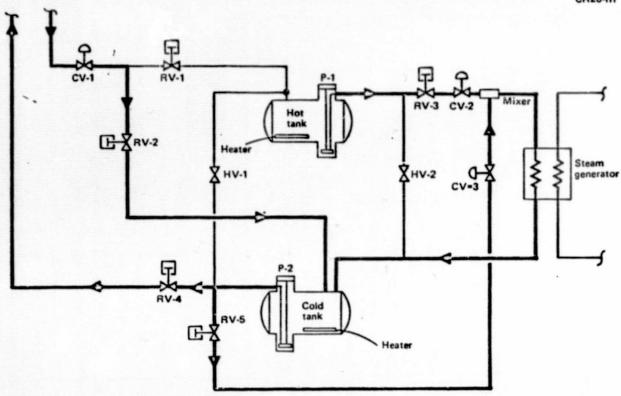


Figure 4.6-4. Startup Mode, Two Tank Configuration

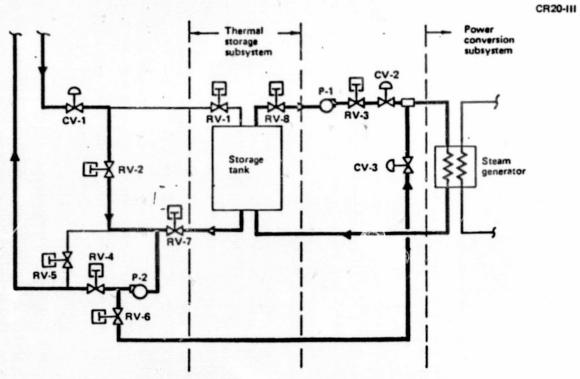


Figure 4.6-5. Startup Mode, Single-Tank Configuration

the tank, pumped through the receiver, and returned to the pump inlet until the fluid leaving the receiver reaches the system operating temperature. Flow is controlled by CV-1 with RV-1 closed and RV-2 open.

During startup, HTS will be drawn from both the top and the bottom of the storage tank to supply the steam generator. Through use of the control valves (CV-2 and CV-3) the steam generator will be gradually warmed up to preclude the problem of thermal shock which would be associated with startup using fluid at the full operating temperature.

#### 4.6.2.2 Normal Operating Mode

## 3.5-Year and 4.5-Year Programs

The normal operating mode is shown on Figure 4.6-6. Hitec will be drawn from the cold tank, pumped through the receiver and returned to the hot tank. The drag valve (CV-1) will serve the dual functions of dissipating the hydrostatic head in the return line from the receiver and controlling the Hitec flowrate to maintain the receiver exit temperature within design limits. All bypass valves are closed.

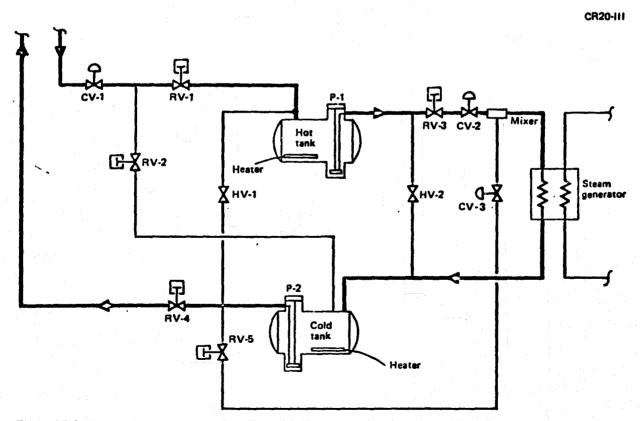


Figure 4.6-6. Normal Operating Mode, Two-Tank Configuration

The steam generator will be supplied with Hitec drawn from the hot tank, pumped through the steam generator, and returned to the cold tank. The control valve (CV-2) in the Hitec line from the hot tank will modulate the flow to maintain the Hitec exit temeprature from the steam generator within design limits.

## 6-5-Year Program

The normal operating mode is shown on Figure 4.6-7. HTS will be drawn from the bottom of the tank, pumped through the receiver, and returned to the top of the tank. The drag valve (CV-1) will again serve to dissipate the hydrostatic head in the return line as well as to control the receiver exit temperature within design limits.

The steam generator will be supplied with HTS drawn from the top of the tank, pumped through the steam generator, and returned to the bottom of the storage tank. The control valve (CV-2) will modulate the flow to maintain the HTS exit temperature from the steam generator within design limits.

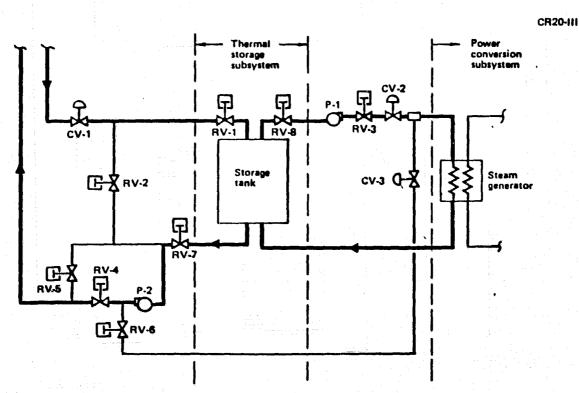


Figure 4.6-7. Normal Operating Mode, Single-Tank Configuration

## 4.6.2.3 Operation From Storage (Intermittent Mode and Extended Operation)

## 3.5-Year and 4.5-Year Programs

In the intermittent mode and for extended operation, the steam generation subsystem will be operated with energy from thermal storage while the receiver loop is inoperative as shown on Figure 4.6-8. Hitec will be drawn from the hot tank, pumped through the steam generator, and returned to the cold tank as long as usable fluid remains in the hot tank. The flow of Hitec to the steam generator will be modulated by the control valve (CV-2) to maintain the Hitec exit temperature from the generator within design limits.

#### 6.5-Year Program

The steam generation subsystem will be operated with energy from thermal storage while the receiver loop is inoperative as shown on Figure 4.6-9. Hitec will be drawn from the top of the storage tank, pumped through the steam generator, and returned to the bottom of the storage tank. Operation will be terminated when the thermocline reaches the top of the tank.

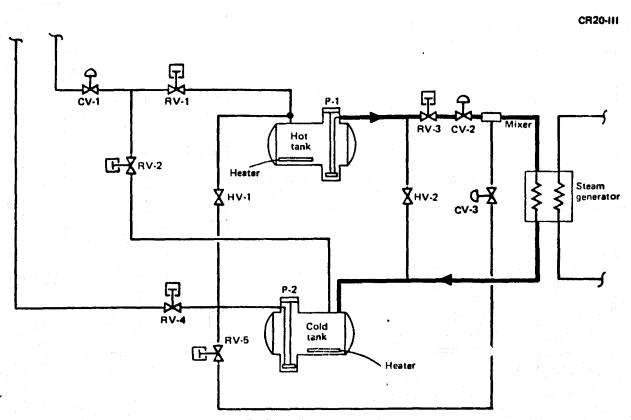


Figure 4.6-8. Operation From Storage, Two-Tank Configuration

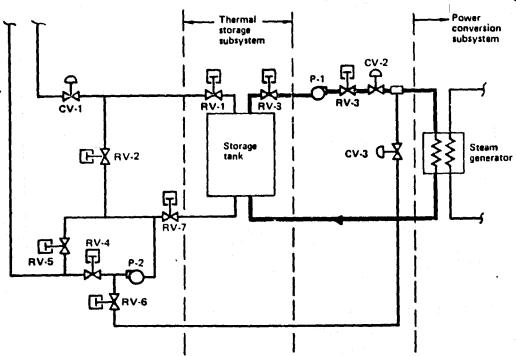


Figure 4.6-9. Operation From Storage, Single-Tank Configuration

The flow of HTS to the steam generator will be modulated by the control valve (CV-2) to maintain the HTS exit temperature from the steam generator within design limits.

#### 4.6.2.4 Normal Shutdown Mode

## 3.5-Year and 4.5-Year Programs

Normal shutdown is shown on Figure 4.6-10. The motorized valves will be operated to partially drain the receiver supply and return lines back into the cold storage tank. This will be done with valves RV-2 and RV-4 open, RV-1 closed, and the cold tank pump (P-2) allowed to back-spin at the Hitec drains into the tank.

The hot tank pump (P-1) which supplies Hitec to the steam generator will be shut down when the level indicator shows the hot tank is empty.

Trace heating will be supplied to the Hitec lines as required to maintain the specified line temperatures during shutdown.

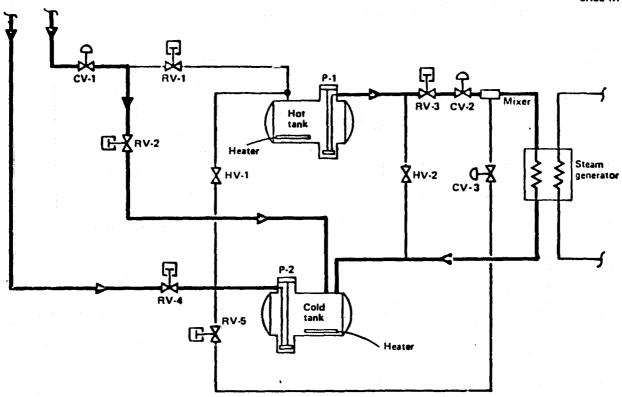


Figure 4.6-10. Normal Shutdown Mode, Two-Tank Configuration

# 6.5-Year Program

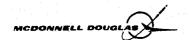
Normal shutdown is shown on Figure 4.6-11. The motorized valves will be operated to partially drain the receiver supply and return lines back into the bottom of the storage tank. This will be done with valves RV-2, RV-5, and RV-7 open, valves RV-4 and RV-1 closed, and the receiver supply pump (P-2) turned off.

The pump (P-1) which supplies HTS to the steam generator will be shut down when the thermocline reaches the top of the tank.

Trace heating will be supplied to the HTS lines as required to maintain the specified line temperatures

# 4.6.2.5 Emergency Shutdown Mode (All Programs)

In this mode, the loop in which a performance abnormality is detected will be completely shut down consistent with maintaining equipment integrity and plant safety. All valves in the subsystem will be closed and the pump will be



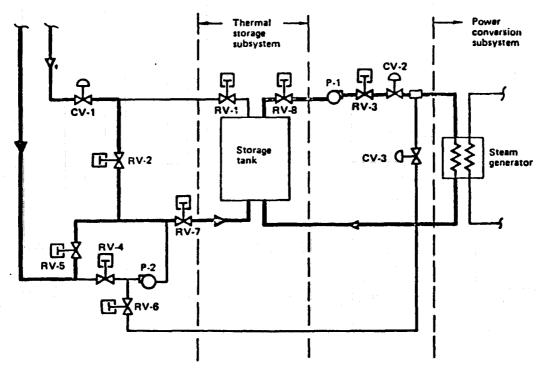


Figure 4.6-11. Normal Shutdown Mode, Single-Tank Configuration

turned off. Checkout and inspection procedures will then be initiated to determine the cause of the abnormality.

Trace heating will be used on the Hitec lines as required to maintain the specified line temperatures during the shutdown.

Due to the separation of the receiver loop and the steam generator loop, only part of the total system will normally be affected by an emergency shutdown of reasonably short duration. If the abnormality appears in the receiver subsystem, the steam generation subsystem can continue to operate until the energy available in thermal storage has been used. If the abnormality appears in the steam generation subsystem, the receiver subsystem can continue to operate until the thermal storage is charged to the limit of its capacity.

#### 4.6.2.6 Standby Mode

# 3.5-Year and 4.5-Year Programs

In this mode, the system will have been shut down for long enough to require heating of the Hitec in the cold tank to maintain it within design limits



so that system operation can be resumed at any time conditions are suitable. The system may be placed in standby mode as a consequence of an extended period of bad weather or the necessity for system repairs. If the shutdown period is sufficiently extended to allow the fluid in the hot tank to cool substantially, it will be pumped to the cold tank and maintained within design limits by the immersion heater.

# 6.5-Year Program

In this mode the system will have been shut down for long enough to require heating of the HTS in the storage tank so that system operation can be resumed at any time conditions are suitable. The system may be placed in standby mode as a consequence of an extended period of bad weather or the necessity for system repairs.

## 4.6.2.7 Extended Shutdown (All Programs)

In this mode Hitec will be purged into storage from the lines. In the 6.5 year program, the fluid will all be pumped into the cold tank. No heating will be applied to the system and the Hitec will be allowed to cool and solidify.

#### 4.7 POWER CONVERSION SUBSYSTEM CHARACTERISTICS

## 4.7.1 Design and Performance Characteristics

The primary function of the Power Conversion Subsystem (PCS) is to convert the thermal energy stored in the Hitec/HTS into electricity. This electrical power is then supplied to the electrical transmission network and is also used to supply power to parasitic plant loops.

The major components of the PCS are:

- Turbine-generator and ancillary equipment
- Steam generator
- Feedwater heaters and piping
- Pumps
- Condenser and air removal equipment
- Heat rejection equipment
- Water treatment
- Auxiliary power unit
- Instrumentation and control valves
- Switchgear and plant electrical network
- Wastewater pond

All components of the PCS have been selected on the basis of minimum hardware development requirements and are off-the-shelf with the exception of the radial turbine.

A survey of vendors to determine the availability and applicability of various steam turbines resulted in the selection of two candidate types. These are:

- A. A multistage, high-efficiency, marine turbine-generator set, capable of accepting steam at the high temperatures and pressures required for high cycle efficiencies. This type of machine is being considered in the 3.5 and 4.5-year programs.
- B. A radial outflow turbine under development by Energy Technology, Inc. (ETI) that will outperform the marine turbines by a significant amount. This machine is being considered for the 6.5-year program.



Based on the above turbine candidates, the analysis and design of the water/
steam loop and other PCS equipment for the experimental plants was addressed.
The PCS performance shown in the schematics (Section 4.1, Figures 4.1-2 to
4.1-5) and presented in tabular form in Table 4.1-1 are based on the designs
developed for the candidate turbines by Stearns-Roger.

Piping and instrumentation diagrams of the feedwater/steam loop for the three programs are shown in Figures 4.7-1 through 4.7-3. A brief description of the function of the loop follows.

Thermal energy is supplied to the PCS through the steam generator. Hitec/HTS is fed to the steam generator, where it passes through the superheater, boiler, and preheater shells in a series arrangement and generates superheated steam at design conditions. The pressure and temperature of the steam is regulated by modulation of the Hitec/HTS flow rate through the superheater, boiler, and preheater. This steam is fed to the turbine through emergency stop and control valves in series. Steam is expanded through the turbine and extracted at one or more locations and pressures and used for deaeration and feedwater heating. The steam exhaust from the turbine enters the condenser and is condensed at a temperature of 42°C or less. Condenser vacuum is maintained by the use of a mechanical vacuum pump. The water level in the hot well is maintained by a level control valve which controls make-up water addition from the condensate storage tank. The level of water in the condensate storage tank is maintained by the demineralizer control system which activates the demineralizer when the storage level falls below a specified quantity. Condensate can also be returned to the storage tank by opening a gate valve located at the condensate pump discharge. The condensate is pumped through the condensate polisher (and closed feedwater heaters in the radial turbine design) and delivered to the deaerator at a rate which is controlled by a deaerator level control. During low flow situations such as start-up, condensate is also recirculated to the condenser through a flow restrictor.

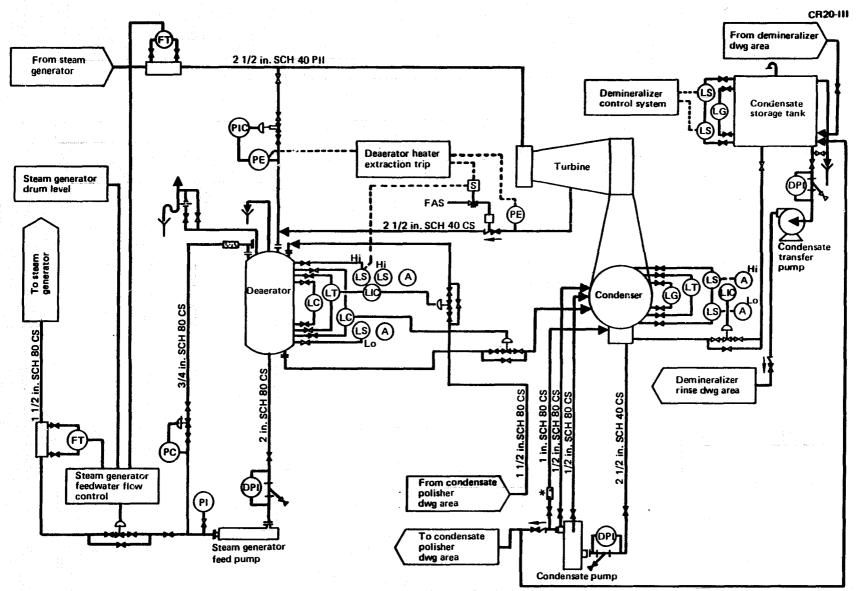


Figure 4.7-1. Piping and Instrumentation Diagram for Power Conversion System—3.5-Year Program

4-120

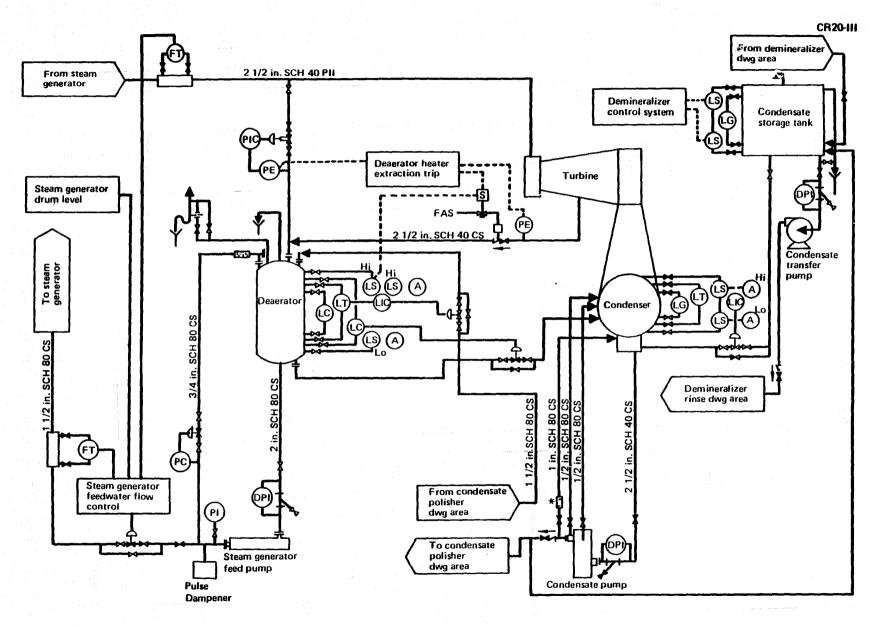


Figure 4.7-2. Piping and Instrumentation Diagram for Power Conversion System-4.5-Year Program

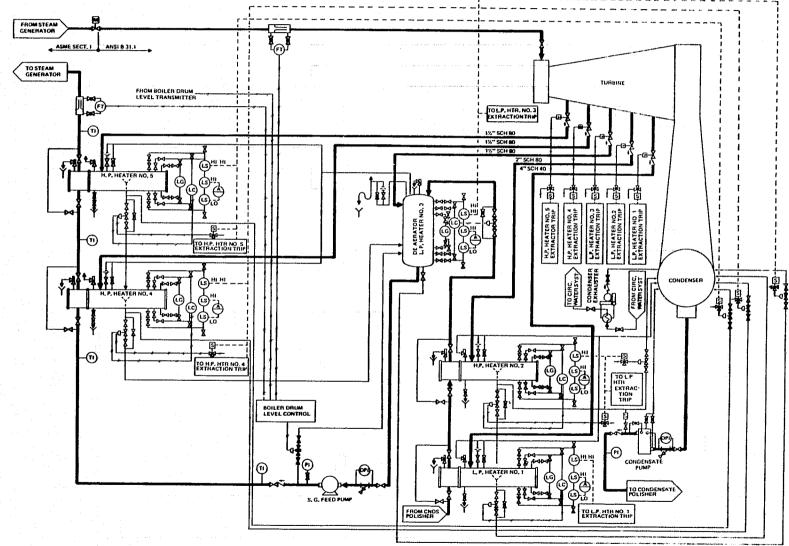


Figure 4.7-3. Steam, Condensate, Feedwater, Extraction Steam, Heater Vents, and Drains Flow Diagram for 6.5-Year Program

The deaerator also has a line leading back to the condenser to allow condensate to be dumped to the condenser if the deaerator becomes flooded. Extraction steam enters the deaerator, then raises the temperature of the condensate to saturation temperature. This saturated feedwater then enters the steam generator feed pump and is pumped to a pressure which is controlled by a recirculation line and valve. A control valve then regulates flowrate into the steam generator based on signals from flowrate transmitters and the boiler drum level transmitter. The feedwater then passes through the preheater and enters the boiler where it is converted to saturated steam, enters the superheater and is finally delivered to the main steam line.

### 4.7.1.1 Turbine/Generator

The turbine to be used in the baseline (3.5-year program) system is a high speed (9,000-10,000 rmp), multistage unit capable of expansion efficiencies (mechanical shaft energy/isentropic enthalpy change) of 0.70 to 0.71. The first stage of the turbine is of the Curtis type followed by four to seven Rateau-type stages. A single uncontrolled extraction port is provided for feedwater heating. These marine turbines are designed for high availability, ruggedness, and rapid start-up.

Reduction gearing is typically a single reduction type with single or double helical gears and will reduce shaft speed to 1800 rpm. This type of gearbox has an efficiency of approximately 0.98. The generator, turbine, condenser and gearbox are assembled at the factory on a skidplate together with all necessary ancillary equipment and then factory-tested before shipment. Ancillary equipment includes gear driven gil pump, electric motor oil pump, oil cooler, filters, oil tank, and generator control unit including switchgear. The turbine comes complete with governor, emergency stop and governing valve and overspeed protection. A schematic representation of the steam path, lubrication and control system is given in Figure 4.7-4 and a cutaway illustration of a typical marine turbine is shown in Figure 4.7-5A. Candidate turbines for the baseline system are discussed in Volume V.

An axial turbine capable of expansion efficiency of 0.75 with steam inlet conditions of 510°C, 103 bars, is specified for the 4.5-year program. The goal of 0.75 expansion efficiency should be obtained as a result of a



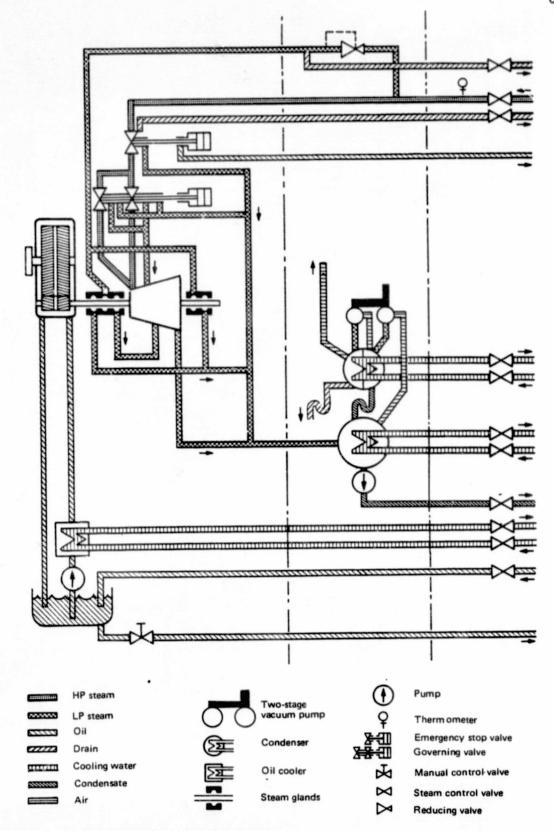
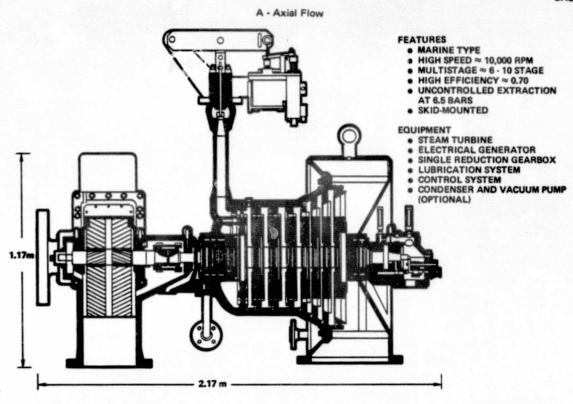
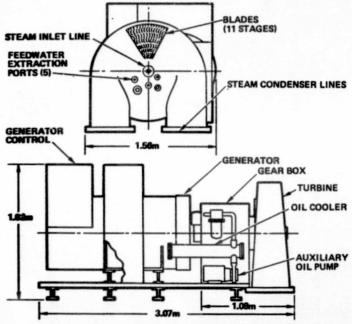


Figure 4.7-4. Turbine Steam and Lubrication Diagram



# B - Radial Outflow



#### **FEATURES**

- HIGH SPEED 12,000 RPM
- MULTISTAGE 11 STAGE
- HIGH EFFICIENCY 0,84
- FIVE UNCONTROLLED EXTRACTION PORTS
- SKID-MOUNTED

## **EQUIPMENT**

- STEAM TURBINE
- ELECTRICAL GENERATOR
- LUBRICATION SYSTEM
- GEARBOX
- CONTROL SYSTEM

Figure 4.7-5. Turbine Description

development program now being sponsored by the DOE to develop a high efficiency advanced steam turbine. This device will operate at 12,000 rpm and employ epicyclic gearing.

The radial outflow turbine designed by ETI will be used in the 6.5-year program. It is a high-speed (12,000 rpm), 10-stage unit capable of expansion efficiencies of 0.84 when fully developed and tested as part of the 6.5-year program. Five uncontrolled extraction ports will be provided for feedwater heating. The reduction gearing will be a double reduction with double helical gears and will reduce shaft speed to 1,800 rpm. This type of gearbox has an efficiency of approximately 0.98. The turbine and gearbox will be assembled at the factory and tested before shipment. Lubrication will be provided by a motordriven oil pump. A pressurized reservoir will be included to provide lubrication in the event of a pump failure. The radial turbine-generator is shown in Figure 4.7-5B.

Turbine design conditions for the three programs are summarized in Table 4.7-1.

## 4.7.1.2 Condenser and Air Removal Equipment

The condenser selected for the three designs is of the two pass shell and tube type using cooling tower circulating water for heat rejection. Tube material will be admiralty or a similar alloy. The condenser is sized for the highest heat rejection load that can be expected during full load operation. The heat rejection loads governing the condenser sizing are based on turbine exhaust flow conditions and steam generator thermal input minus extracted mechanical energy. A summary of the condenser design parameters for the baseline and three alternate designs is given in Table 4.7-1.

The air removal equipment is required to remove air, nitrogen, and other noncondensible gases from the steam side of the condenser. This will be accomplished using a mechanical vacuum pump with electric motor drive. The mechanical vacuum pump was selected instead of a steam jet ejector due to the lack of steam at start-up and to provide operational flexibility.

### 4.7.1.3 Steam Generator

The steam generator consists of separate preheater, boiler and superheater sections. The preheater section consists of two two-pass U-tube heat exchangers



Table 4.7-1. Turbine-Generator-Condenser Design Summary

Characteristics	3-1/2 year axial	4-1/2 year axial	6-1/2 year radial
Overall			
Power Output, Gross	1,135 KWe	1,110 KWe	1,080 KWe
Net	1,000 KWe	1,000 KWe	1,000 KWe
Output Voltage			
Generator	<del></del>	4160 V	
Auxiliary Transformer	4	480 V	
<u>Turbine</u>			
Inlet Steam Conditions			
Pressure, Bars, (psia)	62 (900)	103 (1,500)	121 (1,750)
Temperature, °C, (°F)	427 (800)	482 (900)	510 (950)
Throttle Flow, kg/hr (1b/hr)	<b>5,977</b> (13,180)	4,900 (10,803)	4,407 (9,717)
Condenser			
Туре		— Two Pass, Tube and Shell	
Tube Material		Admiralty	-
Surface, m <sup>2</sup> , (ft <sup>2</sup> )	41.8 (450)	33.4 (360)	23.4 (250)
Tube Diameter, cm, (in.)		2.54 (1.0	)
Tube Wall Thickness	· •	18 Bwg —	
Tube Length, m, (ft)		3.14 (10.	3) ———
Condenser Pressure, Bars (in. Hg A)		0.085 (2.	5)
Heat Rejection (MWt)	3,11	2.47	1.75
Cooling Water Flow, Kg/hr (gpm)	535,000 (2367)	425,000 (1881)	301,000 (1332)
Cooling Water Cut °C, (°F)	•	34.4 (94)	
Cooling Water In °C, (°F)		29.4 (85)	-

with a longitudinal baffle on the shell side. The boiler will be of the natural recirculation type with an elevated drum to provide separation of the steam and water. The superheater section is composed of a u-tube heat exchanger with longitudinal baffle. A schematic diagram of the steam generator, instrumentation and controls is shown in Figure 4.7-6 and the preliminary design and operating parameters given in Table 4.7-2. Also included in the steam generator is a line and control valve permitting the steam drum to blow down for removal of water impurities.

#### 4.7.1.4 Feedwater Heaters

The 3.5 year and 4.5 year PCS have a design utilizing a single feedwater heater in the form of a direct contact spray deaerator utilizing stainless steel trays and a carbon steel shell. This unit is designed to reduce dissolved oxygen to less than 0.005 cc/l and is sized to provide 10 minutes of feedwater at design flow rate. It will be elevated sufficiently to supply the required head to the boiler feed pump. This unit will be purchased as a skip-mounted package complete with level controller and valve, safety valve, pneumatic drain valve and level switches and alarm.

The radial turbine PCS utilizes five feedwater heaters consisting of one deaerator, two low-pressure closed heaters, and two high-pressure closed heaters. Tube material used in the low-pressure heaters is 90-10 Cu-Ni; carbon steel was selected for the high-pressure heaters. The 90-10 Cu-Ni alloy was selected over stainless steel because of better heat-transfer capabilities. A summary of the design parameters of the feedwater heaters is given in Table 4.7-3.

#### 4.7.1.5 Pumps

The PCS includes five pumping stations in the water/steam loop. These are

- (1) steam generator feedpump, (2) condensate pump, (3) circulation water pump;
- (4) condenser exhauster vacuum pump, and (5) condensate transfer pump. The design requirements and characteristics of each of these pumps are defined in Table 4.7-4. In all cases, a single full-capacity pump is used (see trade study in Volume V).

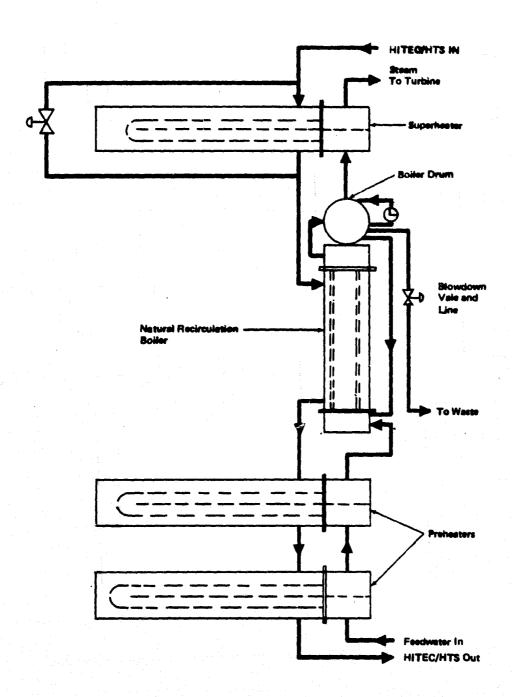


Figure 4.7-6. Steam Generator Schematic

Table	4.7-2.	Steam	Generator	Summary
			and the second s	

	Characteristic	3-1/2 year axial	4-1/2 year axial	6-1/2 year radial
0ve	rall Steam Generator			
	Туре	→ Natural reci	irculation with separate preheate	er and superheater 🕳
	Duty, MWt	4.24	3.58	2.83
Pre	heater Section			
	Configuration	<b>←</b> Two	o-identical horizontal U-tubes i	
	No. of Passes		2	
	Mean Surface Area, m <sup>2</sup> (ft <sup>2</sup> )	12.1 (130)	12.5 (135) 7.65 (83)	31.1 (335)
	Tube Size		0.95 cm (3/8 in.) (BWG 18)	· · · · · · · · · · · · · · · · · · ·
	No. of Tubes	42	43	138
	Tube Length Per Pass, m (ft)	<del></del>	2.74 (9)	-
	Tube/Shell Material	<b>4</b>	Carbon steel/carbon steel	-
Boi	ler Section			
	Mean Surface Area, m <sup>2</sup> (ft <sup>2</sup> )	25.1 (270)	19.1 (205)	26.5 (285)
	Tube Size		1.91 cm (3/4 in.) (BWG 16)	·
	No. of Tubes	155	, <b>118</b>	164
	Tube Length, m (ft)		2.95 (9.7)	
	Tube/Shell Material		Carbon steel/carbon steel	
Sup	erheater Section			
	Configuration	<b>──</b> Two	-Identical Horizontal U-tubes Ir	Series
	No. of Passes	•	2	
	Mean Surface Area, m <sup>2</sup> (ft <sup>2</sup> )	(95)	(130)	(160)
	Tube Size	•	1.27 cm (1/2 in.) (BWG 18)	
	No. of Tubes	22	30	37
	Tube Length Per Pass, m (ft)	4	2.74 (9)	
	Tube/Shell Material	CS/CS	304 SS/304 SS	304 SS/304 SS

Table 4.7-3. Feed Water Heater Summary (Page 1 of 3)

Characteristic	3-1/2 year axial	4-1/2 year axial	6-1/2 year radial
Feedwater Heater No. 1			
Duty, KJ/S (Btu/h)	None	None	145 (493,000)
Feedwater Outlet Temp, °C (°F)			80 (175)
Extraction Temp, °C (°F)	The state of the s		<b>82 (180)</b>
Extraction Pressure, Bars (psia)			0.51 (7.4)
Design Shell Pressure, MPa (psia)			1.7 (25)
Heater Drain Temp, °C (°F)			48 (118)
Terminal Difference, °C (°F)			2.8 (5)
Drain Cooler Approach, °C (°F)			5.6 (10)
Design Tube Pressure, Bars (psia)			6.9 (100)
Tube Area, m <sup>2</sup> (ft <sup>2</sup> )			4.36 (46.9)
Feedwater Heater No. 2		• • • • • • • • • • • • • • • • • • •	
Duty, KJ/S (Btu/h)	None	None -	80 (272,000)
Feedwater Outlet Temp, °C (°F)			100 (213)
Extraction Temp, °C (°F)			103 (218)
Extraction Pressure, Bars (psia)			1.15 (16.7)
Design Shell Pressure, Bars (psia)			3.45 (50)
Heater Drain Temp, °C (°F)			<b>85 (185)</b>
Terminal Difference, °C (°F)			2.8 (5)
Drain Cooler Approach, °C (°F)			5.6 (10)
Design Tube Pressure, Bars (psia)			6.9 (100)
Tube Area, m <sup>2</sup> (ft <sup>2</sup> )			2.40 (25.9)

Table 4.7-3. Feed Water Heater Summary (Page 2 of 3)

Characteristic	3-1/2 year axial	4-1/2 year axial	6-1/2 year radial			
Deaerator						
Feedwater In	American Science					
Kg/hr (1b/hr)	4,867 (10,732)	3,974 (8,763)	3,328 (7,338)			
°C (°F)	43 (110)	43 (110)	100 (212)			
J/g (Btu/lb)	181 (78)	181 (78)	418 (180)			
H.P. Htr. Drains In						
Kg/hr (1b/hr)	jej sa 🕶		<b>797</b> (1,757)			
°C (°F)	<b></b>	tion of the second seco	<b>154 (3</b> 09)			
J/g (Btu/lb)			653 (281)			
Steam In						
Kg/hr (1b/hr)	1,100 (2,426)	926 (2,042)	282 (622)			
°C (°F)	230 (447)	213 (416)	154 (310)			
J/g (Btu/lb)	2,912 (1,253)	2,873 (1,236)	2,759 (1,187)			
Feedwater Out						
Kg/hr (1b/hr)	5,977 (13,180)	4,900 (10,803)	<b>4,407</b> (9,917)			
°C (°F)	163 (325)	163 (325)	144 (292)			
J/g (Btu/lb)	688 (296)	688 (296)	<b>607</b> (261)			
Shell Operation						
Pressure, Bars (psia)	6.5 (95)	6.5 (95)	4.1 (59)			
Storage Capacity	4	10 Minutes of Full Flow-				
Туре	<b>4</b>	←				
Material	<b>←</b> S1	Stainless Steel Trays, Carbon Steel Shell-				



Table 4.7-3. Feed Water Heater Summary (Page 3 of 3)

Characteristic	3-1/2 year axial	4-1/2 year axial	6-1/2 year radial
Feedwater Heater No. 4			
Duty, KJ/S (Btu/h)	None	None	193 (659,000)
Feedwater Outlet Temp, °C (°F)			186 (367)
Extraction Temp, °C (°F)			257 (495)
Extraction Pressure, Bars (psia)			12.2 (177)
Design Shell Pressure, Bars (psia)			13.8 (200)
Heater Drain Temp, °C (°F)			172 (309)
Terminal Difference, °C (°F)			2.8 (5)
Drain Cooler Approach, °C (°F)			5.6 (10)
Design Tube Pressure, Bars (psia)			138 (2,000)
Tube Area, m <sup>2</sup> (ft <sup>2</sup> )			5.42 (58.3)
Feedwater Heater No. 5			
Duty, KJ/S (Btu/h)	None	None	294 (1,000,000)
Feedwater Outlet Temp, °C (°F)			243 (470)
Extraction Temp, °C (°F)			374 (706)
Extraction Pressure, Bars (psia)			37.2 (540)
Design Shell Pressure, Bars (psia)			41 (600)
Heater Drain Temp, °C (°F)			192 (377)
Terminal Difference, °C (°F)			2.8 (5)
Drain Cooler Approach, °C (°F)			5.6 (10)
Design Tube Pressure, Bars (psia)			138 (2,000)
Tube Area, m <sup>2</sup> (ft <sup>2</sup> )			6.90 (74.3)

Table 4.7-4. Pump Summary (Page 1 of 3)

Characteristic	3-1/2 year axial	4-1/2 year axial		6-1/2 year radial
Steam Generator Feed				
Туре	Barrel, 37 Stage	. +	– Triplex Plunger –	<del></del>
Manufacturer (Typical)	Goulds	<del></del>	Aldrich	
Model No.	3935 BP40	4	1-1/2 x 3HS3	
Capacity, Kg/hr, (gpm)	5,977 (29)	4,900 (24)		4,407 (21)
TDH, m (ft)	700 (2300)	1220 (4000)		1370 (4500)
Driver Speed, rpm	3500	<del></del>	1750	
Driver Rating, KW (bhp)	30 (40)	4	22.4 (30)	
Efficiency, %	46	+		<del></del>
Power Required, KW (bhp)	23.3 (31)	18.0 (24)		18.9 (25)
Condensate				
Туре	<del>(                                    </del>	Turbine,	25 Stage	
Manufacturer (Typical)	Goulds	Goulds		Goulds
Model No.	VIC 6ALC	VIC 6ALC		VIC 6ALC
Capacity, Kg/hr (gpm)	4,867 (22)	3,974 (18)	A CONTRACTOR OF THE PARTY OF TH	3015 (14)
TDH, m (ft)	76 (250)	76 (250)		60 (200)
Driver Speed, rpm	1760	1760		1760
Driver Rating, KW (hp)	3.7 (5)	3.7 (5)		2.2 (3)
Efficiency, %	60	60		60
Operating Power, KW (hp)	1.7 (2)	1.4 (2)		0.9 (1.2)



Table 4.7-4. Pump Summary (Page 2 of 3)

Characteristic	3-1/2 year axial	4-1/2 year axial	6-1/2 year radial
Circulating Water			
Туре		Vertical Turbine, 3 Stage	<del></del>
Manufacturer (Typical)	Goulds	Goulds	Goulds
Model No.	TBD	TBD	VIT 10LH
Capacity, Kg/hr (gpm)	535,000 (2,367)	425,000 (1,881)	301,000 (1,332)
TDH, m (ft)	10.7 (35)	10.7 (35)	10.7 (35)
Driver Speed, rpm	1760	1760	1760
Driver Rating, KW (bhp)	15.0 (20)	15.0 (20)	11.2 (15)
Efficiency, %	82	82	82
Power Required, KW (bhp)	14.6 (19)	11.6 (15)	8.4 (11)
Condenser Exhauster Vacuum			
Туре	<del></del>	Two-Stage, Liquid Ring	
Manufacturer (Typical)		Nash —	
Model No.	<del></del>	AT-124	· · · · · · · · · · · · · · · · · · ·
Capacity	•	51	
Pump Speed, rpm		1760 —	
Driver Rating, KW (bhp)	4	7.5 (10)	·
Estimated Operating Power, KW (bhp)		6.0 (8)	



Table 4.7-4. Pump Summary (Page 3 of 3)

Characteristic	3-1/2 year axial	4-1/2 year axial	4-1/2 year radial	6-1/2 year radial
Condensate Transfer				
Туре	<del></del>	Horizontal	Centrifugal	
Manufacturer (Typical)	4	Aur	ora ———	·
Model No.	<del></del>	32	1	
Capacity, Kg/hr (gpm)	4	5670	(25)	
TDH, m (ft)	<del>(</del>	23 (	75)	
Driver Speed, rpm	<b>4</b>	35	00	· · · · · · · · · · · · · · · · · · ·
Driver Rating, KW (bhp)	<b>4</b>	1.1 (	1.5) ———	·
Efficiency, %	<del></del>	5	5	
Operating Power, KW (bhp)	4	0.7 (	0.9)	**

#### 4.7.1.6 Heat Rejection

The method of condenser heat rejection selected is mechanical draft, wet cooling tower with a two-speed motor. The cooling tower heat load is assumed equal to the condenser heat rejection load. Cooling towers of the size and capabilities required are available as assembled, skid-mounted units from several manufacturers. The design parameters of the cooling tower for the baseline and three alternate systems are given in Table 4.7-5. Cooling power water requirements are discussed in Volume V. The cooling tower water circuit is illustrated schematically in Figure 4.7-7.

Table 4.7-5. Cooling Tower Summary

Characteristic	3-1/2 year axial	4-1/2 year axial	6-1/2 year radial
Туре	<del></del>	Mechanical Draft	<del></del>
Fan Motor Size, KW, (HP)	22.4 (30)	18.7 (25)	15 (20)
Design Wet Bulb Temperature, °C (°F)	<b>←</b>	23.3 (74)	<b>&gt;</b>
Outlet Water Temperature, °C (°F)		29.4 (85)———	
<pre>Inlet Water Temperature, °C (°F)</pre>	<b>4</b>	34.4 (94)	
Heat Rejection (MWt)	3.11	2.47	1.75
Dimensions, L x W x H, m, (ft)	<del></del>	3.6 x 5.5 x 7 (12 x 18 x 23)	<b></b>

## 4.7.1.7 Water Treatment Equipment

The water treatment equipment includes:

- One single train makeup demineralizer.
- One full-flow powdered resin condensate polisher.
- One boiler chemical feed system.
- One cooling tower chemical feed system.
- One cooling tower control system.
- One boiler water monitoring panel.



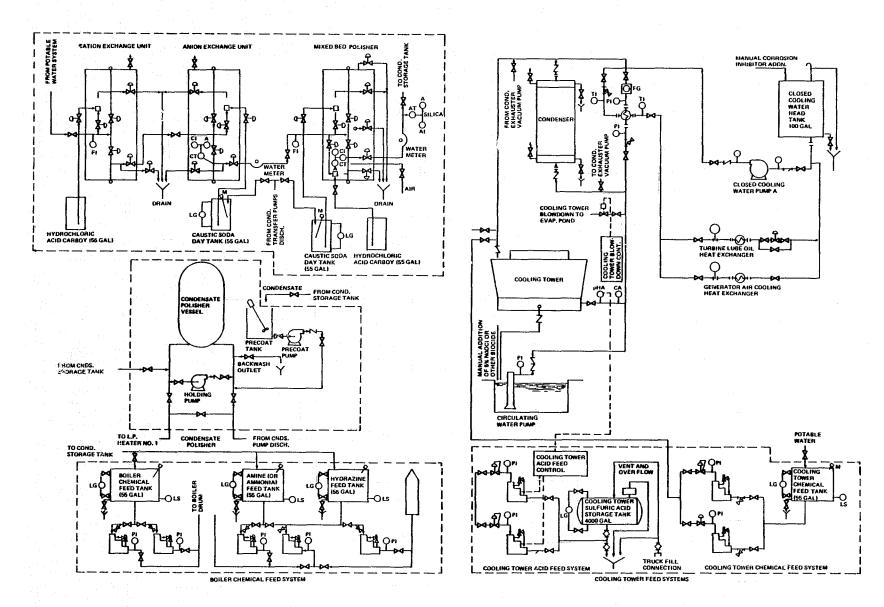


Figure 4.7-7. Water Treatment, Circulating Water and Closed Cooling Water Systems

## Makeup Demineralizer

The makeup demineralizer system will consist of a strongly acidic cation exchange vessel followed by a strongly basic anion exchange vessel followed by a mixed bed exchange vessel. A single train demineralizer feeding a storage tank will provide adequate boiler makeup water since the steam generator makeup requirements are quite modest — between 0.38 and 2.65 m<sup>3</sup> (100 and 700 gallons) per day — and the smallest automatically regenerated package demineralizer of most manufacturers is much larger than required. A condensate storage tank will be provided to store several days makeup requirements so that the demineralizer can be regenerated during operating periods and to allow for equipment down time for repairs. The makeup demineralizer is shown schematically in Figure 4.7-7.

Hydrochloric acid will be used to regenerate the cation vessel and the cation exchange resin in the mixed bed vessel because it simplifies the design and operation of small package demineralizers. When these units are used, the above considerations usually outweigh the higher cost of hydrochloric acid, as compared to sulfuric acid.

# Condensate Polisher

A condensate polisher capable of handling the entire condensate flow will be used in all systems to ensure proper clean-up of the feedwater before beginning normal operation. The filter media will consist of a blend of fibrous material and a nonregenerative powdered resin which will be replaced at weekly or biweekly intervals, as its ability to absorb ions is exhausted. A schematic diagram of the polisher is shown in Figure 4.7-7.

# Steam Generator Chemical Feed System

Chemical feed systems will be provided to feed chemicals to the boiler or preboiler system in order to control the chemistry in the boiler and condensate system. The chemicals to be fed would normally be selected by the plant operations personnel with the advice of a water treatment consultant. Chemical feed systems have been selected on the assumption that three chemical activities will be fed — hydrazine, an amine, and a boiler chemical. The rate at which these chemicals are fed to the water will be controlled automatically. This system is illustrated schematically in Figure 4.7-7.

# Cooling Tower Chemical Feed System

Chemical feed systems will be provided to feed chemicals to the circulating water system to control pH and the tendency of the water to be corrosive and/or scale forming. This chemical feed system is shown schematically in Figure 4.7-7.

Two systems will be provided, one to feed sulfuric acid and one to feed a scale inhibitor. The acid feed system will be controlled by the pH of the circulating water.

# Cooling Tower Control System

A control system will be provided to monitor the conductivity and pH of the circulating water. The control system will blow down the cooling tower in order to maintain a preset conductivity. The pH will also be monitored and the feed rate of sulfuric acid will be controlled to maintain a preset pH.

# Steam Generator Water Monitoring

Water quality will be monitored by the use of local instrumentation, sample cocks, analyzers and recorders. The water monitoring instrumentation will include:

Silica analyzer for the boiler water sample (1).

Silica analyzer for the demineralizer effluent sample (1).

pH analyzer for the boiler water sample (1).

pH indicator for the condensate polisher inlet sample (1).

pH indicator for the condensate polisher outlet sample (1).

Specific conductivity analyzer for the boiler water sample (1).

Specific conductivity analyzer for the condensate polisher outlet sample (1).

Cation conduct vity analyzer for the condensate polisher inlet sample (1).

Cation conductivity analyzer for the condensate polisher outlet sample (1).

Dissolved oxygen analyzer for the deaerator outlet sample (1).

Sodium analyzer for the steam sample (this could also be used for the condensate polisher inlet or outlet) (1).

Three-pen recorder (1).

Two-pen recorder (1).

One-pen recorders (6).

Annunciator (1).

## 4.7.1.8 Electrical Network

The plant electrical network is designed to provide the needed power to the electrically powered elements of the system when the plant is operating or not operating. The plant electrical network must also be capable of providing a source of emergency power to critical components in the event of loss of power from both the grid and main plant generator.

A preliminary design for the electrical network architecture and principal elements are shown in Figure 4.7-8. For purposes of this design, it was assumed that the main generator and local grid are both at 4,160 V. This eliminates the need for a transformer between the grid and the generator and requires only the use of circuit breakers in the manner indicated on the left side of the figure.

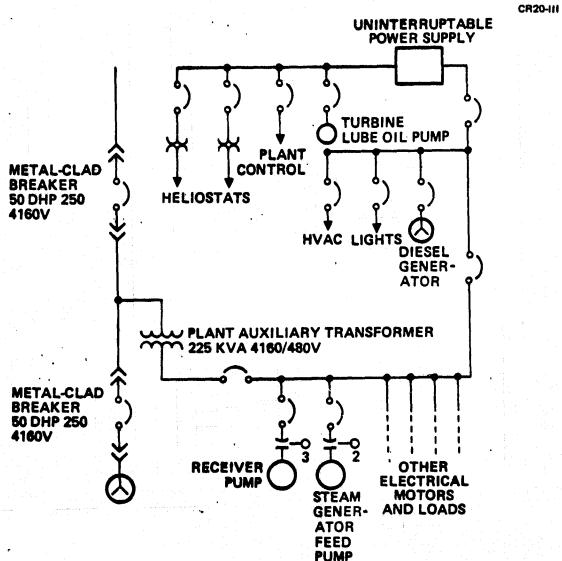


Figure 4.7-8. Electrical One-Line Diagram

The plant electrical power is drawn form the generator — grid tie-in and stepped down in voltage to 480 V. In this manner, power can be drawn from either the grid or main plant generator (when it is operating) even though one of the two metal clad breakers are open.

The motor control center is divided into a main and emergency power bus. The main bus supplies power to all motors and miscellaneous electrical equipment which are not vital to plant operation during periods of emergency shutdown. Those items which must be powered during an emergency shutdown or extended shutdown period, when connection with the grid and main generator are lost, are connected to the emergency bus which can also receive power from an emergency diesel generator set. When power is lost from both the main generator and grid, the breaker connecting the two buses opens and the emergency generator is started. By first opening the breaker, no provisions must be made to synchronize the emergency generator with any spurious currents coming through the main bus. As shown, the emergency bus also powers the uninterruptible power supply (UPS), which in turn supplies uninterruptible power to the control processors, the turbine lube oil pump, and the heliostats.

A tabulation of the anticipated auxiliary power requirements are shown in Table 4.7-6. The tabulation depicts both anticipated daytime and nighttime operation as well as nighttime standby and emergency AC power requirements. These values are used to estimate the capacity for the plant electrical network, transformers, breakers, and diesel generator.

A summary of plant electrical equipment is given in Table 4.7-7.

Table 4.7-6
SYSTEM AUXILIARY LOADS

	Program	3 1/2 Year	4 1/2 Year	6 1/2 Year
Peak Auxilia	ry Load (KWe)	135	110	80
Standby Load	(KWe)	16	<b>9</b>	16
Emergency Lo	ad (KWe)	41	33	34

Table 4.7-7. Electrical Equipment Summary

Characteristic	3-1/2 year 4-1/2 year axial axial	6-1/2 year radial
Diesel Generator		
Output	480 V, 45 KWe or 125	KWe
Motor Control Center		
	Size 2 FVNR - Size 3 FVNR -	3 required 10 required 4 required 1 required 4 required
Plant Auxiliary Transformer		
	Dry type, 150°C ri	se
Switchgear		
	Metal clad 50 DHP and relaying -	2 required
Miscellaneous Equipment		
	Battery, charger and inverted Surge protection Lighting Distribution transformer, 9 Heliostat transformer, 15 KV/ Cable Trays and conduit	KVA
Plant Air Compressor		
Туре	Two cylinder reciproc	ating———
Manufacturer (Typical)	Ingersoll-Rand-	
Capacity, L/min (SCFM)	1560 (55) —	· · · · · · · · · · · · · · · · · · ·
Pressure, bars (psig)	8 (100)—	
Receiver Capacity Liters (gal)	1600 (425)	· · · · · · · · · · · · · · · · · · ·
Driver Rating, KW (bhp)	<del></del>	<del></del>
Operating Power, KW (bhp)	12 (16)	
Instrument Air Dryer	- 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1	
Туре	Heat regenerated dual towe timer controlled	
Manufacturer (Typical)	Electrodryer—	
Mode1	← DE 1/2 —	

#### 4.7.1.9 Instrumentation and Controls

The instrumentation of the PCS will consist of the temperatures, pressure, flowrate and level sensors required to monitor the operating parameters of the fluid loops and voltage, frequency and current sensors for control of electrical generator output. The control valves will be operated pneumatically with the exception of the axial turbine control and emergency valves which are hydraulically actuated. A discussion of instrumentation and control is presented in Section 4.8.

Pressurized air is supplied to the valves by an air compressor as described in Table 4.7-7 which feeds a storage tank. The storage tank dampens the pressure pulses of the reciprocating compressor and provides a continuous air supply should a loss of electrical power occur. The air is dried by a dessicant-type instrument air dryer which is also described in Table 4.7-7.

# 4.7.2 Operational Characteristics

## 4.7.2.1 Start-Up Mode

It will be necessary to follow a start-up procedure every morning. This will entail warm-up of the steam generator, warm-up and clean-up of the water/steam deaerator-condenser loop, run-up of the turbine to speed and application of load. An outline of start-up procedure follows.

# Steam Generator Start-Up

- 1. Salt is slowly circulated to warm up the tubes until natural circulatis established.
- 2. After circulation is established, boiler feedpump is started and shutoff valve to steam generator opened. Steam is sent to deaerator.
- 3. As soon as steam temperature matches turbine temperature, run-up begins.
- 4. Salt temperature and boiler pressure-temperature are raised at a rate fixed by steam generator or turbine stress considerations.

# Turbine Start-Up Procedure

- Start cooling water pump.
- 2. Start condensate pump and recirculate water through condensate polisher, if required, and through deaerator-feedwater heater train.



- 3. Start condenser exhauster pump (if not already started) and exhaust nitrogen blanket gas.
  - 4. Open shutoff valves in steam supply lines.
  - 5. Check oil level and purity and start electric oil pump.
  - 6. Open cooling-water supply valves to and from the oil cooler.
- 7. Check instrumentation to determine when inlet and exhaust steam conditions are correct for start.
  - 8. Check that steam line drain valves are open.
  - 9. Adjust gland steam flow.
- 10. Check emergency overspeed and axial displacement trips are set and governor is operational.
  - 11. Check steam temperatures, when dry close drain valves.
  - 12. Check oil temperature and pressure.
  - 13. Start turbine slowly; run up to 10-15 percent of normal speed.
  - 14. Run at low speed for at least ten minutes.
- 15. Gradually run up to full speed, synchronize, and apply load (5-30 minutes).

## 4.7.2.2 Normal Operation Mode

The normal operating mode occurs when the PCS is supplying 300-1000 KWe to the electrical transmission network and also supplies plant auxiliary loads. The plant control subsystem will monitor the operating parameters of the PCS and automatically adjust steam and Hitec/HTS flow rates based on power demand.

The turbine will be operated in a "turbine lag" mode where changes in turbine output will be initiated by a change in the flow rate of Hitec/HTS to the steam generator. The turbine throttle valve will regulate upstream steam pressure. As Hitec/HTS flow to the steam generator increases, steam pressure will build which will cause the turbine throttle valve to open, thus allowing more flow through the turbine and an increase in power output.

#### 4.7.2.3 Normal Shutdown

The normal shutdown procedure will be implemented each day when demand for electricity is reduced or when storage is exhausted. This will entail removing load and stopping the turbine, shutdown of the steam generator and water/steam loop and preparation for any scheduled maintenance. An outline of shutdown procedure follows.



- 1. Reduce load on generator and open the generator breaker.
- 2. Stop the turbine and check that electric oil pump starts.
- 3. Stop supply of Hitec/HTS to steam generator.
- 4. Shut steam emergency cut-out valve. Shut valves in exhaust line and gland steam lines.
  - 5. Shut steam supply valves.
  - 6. Open turbine drain valves.
  - 7. Shut off supply of cooling water to the oil cooler.
  - 8. Break vacuum with nitrogen.
  - 9. Stop electric oil pump after one hour.
  - 10. Check that steam generator immersion heater is functional.

## 4.7.2.4 Emergency Shutdown

During normal operation the plant control subsystem shall be monitoring many of the important operating parameters of the PCS (steam properties, flow rates, turbine output, etc.). This, in conjunction with independent monitoring systems (level alarms, overspeed trips, vacuum trips, etc.) shall inform the plant operator of any malfunction in the PCS. Depending on the severity of the malfunction, the turbine emergency stop valve may be tripped or an alarm sounded giving the operator a chance to remedy the problem, follow a normal shutdown procedure or trip the emergency stop valve.

## 4.7.2.5 Standby Mode

Following normal shutdown or emergency shutdown procedures, the PCS will be placed in a standby mode. In the standby mode, the turbine, condenser and feedwater heating loop will be blanketed with nitrogen to prevent oxidation and keep feedwater free of oxygen. The immersion heater will maintain temperature of Hitec/HTS in the steam generator at a temperature sufficiently greater than the melt point. Preventive maintenance and inspection shall be scheduled for this period whenever possible.

#### 4.7.2.6 Extended Shutdown Mode

The PCS may occasionally be shut down for extended periods to provide for maintenance, repair, equipment modification, or other causes. This mode is similar to the standby mode with the exception that the Hitec/HTS is drained from the steam generator into the storage tanks.



#### 4.8 PLANT CONTROL SUBSYSTEM DESCRIPTION

This section describes the plant control subsystem including subsystem control. Trade studies and analyses leading to this design are contained in Volume V, Section 9.

## 4.8.1 Design and Performance Characteristics

The Plant Control Subsystem provides the controls, monitors and interfaces for the operation of all the subsystems from a single central point. The Plant Control Subsystem provides for: 1) controlling all factors of each subsystem, 2) monitoring all essential parameters of each subsystem, the protection and safety of the subsystem components, and 3) the integration of the subsystem controls into a coordinated plant operation.

The control and instrumentation functions are provided via: 1) the central control console, 2) redundant minicomputers and peripheral equipment, 3) the field and heliostat microprocessor based controllers of the concentrator subsystem, and 4) the central control unit and remote data acquisition and controller units of the Plant.

Individual remote control units interact directly with the subsystem components and are located strategically in the proximity of components. The concentrator subsystem houses the field and heliostat controllers on the heliostat pedestal and the remote plant controllers are grouped strategically at remote stations throughout the plant and housed in weather proof enclosures. Independent serial signal communications networks separate the control of the collectors (heliostats) and the plant processes.

The remote units, distributed in the plant, contain the electronics to convert actuator and instrument signals to a form that can be used by Micro and Minicomputer systems of the control system and conversely, convert digital signals output by the computer systems to electrical forms usable by the controlling components. The remote units are associated with the central operator control station and interact with central control in a distributed control approach as necessary. The central operator control station provides a command and status capability for the operator.

The implementation of the Plant Control is partitioned off into two distinct areas of responsibility:

- 1) Control and monitoring of the concentrator subsystem collectors.
- 2) Control and monitoring of the plant processes.

The design architecture of the Plant Control system is shown in Figure 4.8-1. A redundant minicomputer with associated peripherals provides a central common interface for both areas of control responsibility. The redundant computers provide: 1) the control commands and status monitoring for the sun tracking collectors in the Concentrator Subsystem, 2) the coordinated control and monitoring of the plant processes collecting, storing, transporting, and 3) the operator interface for monitoring, recording, reporting and controlling the components of the plant.

The computer systems are programmed to provide the operator two modes of command and control for both the collector and plant process control areas.

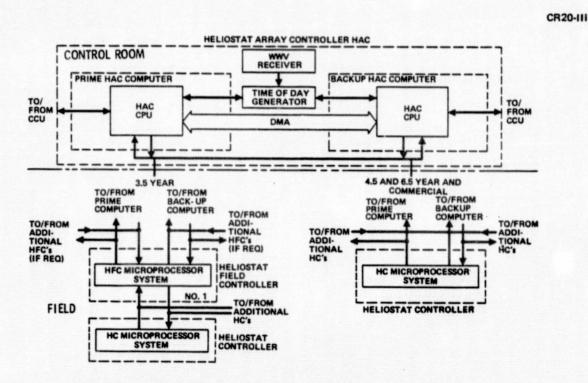
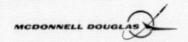


Figure 4.8-1. Design Architecture for Collector Control



These operating modes are:

Automatic - No operator interaction required.

Semiautomatic - Operator interaction required at decision making points. Because there is a significant number of collectors in the field (ranging from approximately 140 to 217) with requirements to maintain single beam and collector safety at all times and operate the Plant with a single person, the primary operating mode of the collector is automatic. A semiautomatic mode for collector operation is provided to permit the operator to move a single heliostat or a group of heliostats for maintenance, checkout alignment, calibration or emergency purposes.

Similarly, the Plant process control and monitoring is accomplished semiautomatically with capability for automatic operation in a coordinated manner using the process computers. The degree of automated control to be implemented varies with the program selection. Automated operations are included for each program, providing the basic software architecture and hardware systems to automatically control transitions between steady state modes for the 3.5 year system to complete unattended plant operation for the commercial plant.

A third mode of Plant operation is used for control of Plant processes. This mode is defined as:

Manual - Operator interaction at each step or sequence of the operating procedure.

This mode is used when the Plant process computer is inoperative and where checkout and test of individual controls and components is required.

The automation characteristics for the 3.5-year, 4.5-year, 6.5-year and commercial plants are shown in Figure 4.8-2.

## 4.8.1.1 Collector Control Components

The major components of the collectors for the 3.5-year program have been selected from the design that will be implemented for the Solar Pilot Plant Program under DOE contract at Barstow, California. These controls consist of the following major components:

- Heliostat Array Controller (HAC)
- Heliostat Field Controller (HFC)
- Heliostat Controller (HC)



	3.5-YEAR SYSTEM	4.5-YEAR SYSTEM	6.5-YEAR SYSTEM	COMMERCIAL SYSTEM
CONCENTRATOR				
PRIMARY	• AUTOMATIC	• AUTOMATIC	• AUTOMATIC	& AUTOMATIC
ALTERNATE	• SEMIAUTOMATIC	• SEMIAUTOMATIC	• SEMIAUTOMATIC	• SEMIAUTOMATIC
PLANT				
PRIMARY	MANUAL	MANUAL	• SEMIAUTOMATIC	AUTOMATIC (UNATTENDED)
FIRST ALTERNATE	• SEMIAUTOMATIC	• SEMIAUTOMATIC	• AUTOMATIC *	• SEMIAUTOMATIC
SECOND ALTERNATE	• AUTOMATIC *	• AUTOMATIC *	• MANUAL	MANUAL
CONTRIBUTION TO COMMERCIAL CONFIGURATION	BASIC SOFTWARE     ARCHITECTURE     FOR AUTOMATION     OPERATING	• SAME AS 3.5 YEAR	OPERATION     TO TEST     AUTOMATED     OPERATION	
	EXPERIENCE NEED TO QUANTIFY PLANT AUTOMATION		;	

. LIMITED

Figure 4.8-2. Plant Control Operational Modes

The design architecture of this control system was shown in Figure 4.8-1. These components are fully developed and will not require any further development or testing to adapt to the EE No. 1,3.5 year program requirements.

#### Heliostat Array Controller

The heliostat array controller (HAC) consists of a redundant minicomputer and associated peripherals all of which are located in the central control room. This equipment provides: (1) the operator interface to the collectors (CRT display and keyboard), (2) the storage media for archiving data and programs (moving head disk), (3) a time-of-day clock synchronized with WWV time and used for sun tracking and data correlation, (4) a printing device to log status and generate reports, (5) a high speed parallel word communications channel linking both processors and used to facilitate automatic transfer of data and status precluding a CPU failure and (6) serial input/output channels connecting the HAC with the heliostat field controllers. A block diagram of the Heliostat Array Controller is shown in Figure 4.8-3.



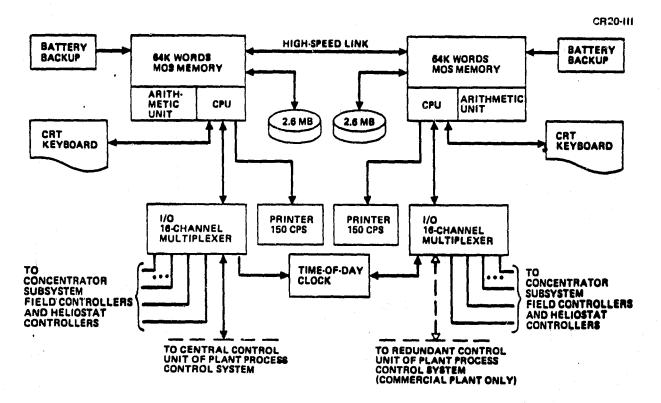


Figure 4.8-3. Plant Control Design Details Computer System (HAC)

One serial I/O channel of each processor is connected to the Central Control Unit (CCU) and supports communications for coordinated control of the other plant functions. Another serial I/O channel of each processor is dedicated to receiver trip circuit communications, and serves to notify collector control that the receiver has reached the limit temperature wherein the heliostats must be removed from receiver track.

The heliostat array controller for the 4.5 year and 6.5 year and commercial programs consists of the same hardware configuration described for the 3.5 year program. However, the applications software is modified for the 4.5 year, 6.5 year and commercial programs to include the functions of the heliostat field controller. This modification provides a more cost effective and reliable control system, using fewer components and providing redundancy through the field controller level.

# Heliostat Field Controller

The Heliostat Field Controller (HFC) is a microprocessor based control element capable of servicing from one to thirty-two heliostats. The HFC is composed of two circuit boards (processor board and memory board) mounted on a mother board and housed in a weather proof enclosure mounted on a heliostat pedestal. A diagram of the HFC mounting arrangement is shown in Figure 4.8-4.

Redundant serial communications links conforming to the telephonic RS232C specifications tie the HAC to the field controller. A single serial communications link ties the field controller to each of the heliostat controllers in the assigned group. Telephonic data transmission techniques are used for each communications link, operating at rates up to 9600 baud.

## Heliostat Controller

The heliostat controller (HC) provides the intelligence to control and monitor the status of a single heliostat. The HC incorporates a microprocessor with a combination of programmed read only memory (PROM) and random access memory (RAM) on a single circuit board to step the tracking motors, monitor position and determine gimbal axis rotation limits.

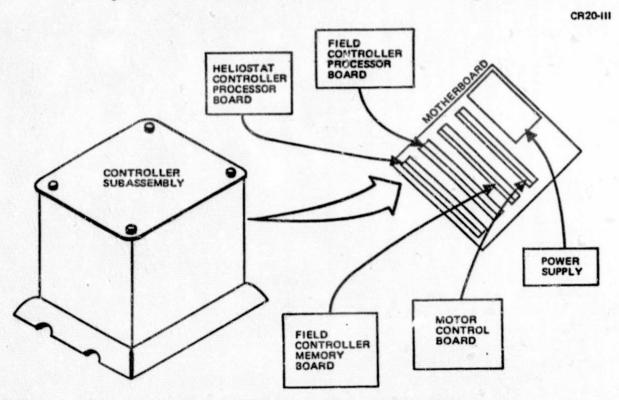


Figure 4.8-4. Diagram of HFC Hardware Mounting Arrangement

The heliostat controller is located on each heliostat pedestal in a weather proof housing and coexists with a motor control circuit board and a power supply. The mother board provides the data communications and power pathways between the HC processor board and the motor control board. The heliostat housing and mother board also accommodates the HFC electronics for the 3.5 year program.

#### 4.8.1.2 Collector Control Functions

The collector controls of the concentrator subsystem provide and distribute the control and monitor functions as characterized by the diagram of Figure 4.8-5.

The application of this functional distribution and software architecture for the 3.5 year program duplicates the configuration control functions designed for the 10 MW Solar Power Pilot Plant at Barstow, California. Consequently, for a short program allocated eight months of development time, this design brings a no risk solution to collector control.

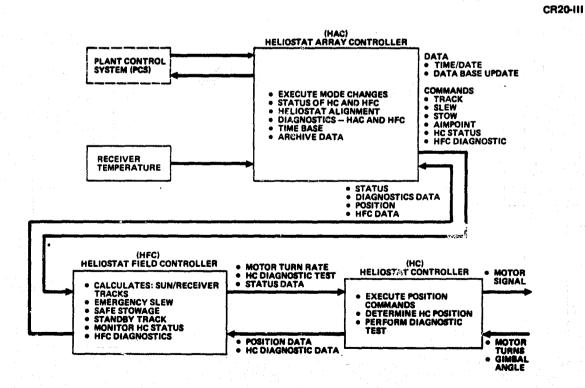


Figure 4.8-5. Collector Control Functions

The 4.5-year, 6.5-year, and commercial programs will integrate the functions of the HFC with the HAC functions, and eliminate the HFC hardware. Sufficient systems development time is available in either of these programs to integrate the HAC and HFC functions thereby reducing hardware cost and increasing the collector control reliability (reduced number of components). This configuration also improves the availability of the HFC functions through the functional redundancy of the dual processor HAC configuration.

These functions are implemented with software in the HAC, HFC and HC processors. The HAC utilizes a commercially available multitasking real time operating system. This architecture and the software architecture of the HFC includes executive, task scheduler and data base management systems. A diagram of this architecture is shown in Figure 4.8-6.

#### 4.8.1.3 Plant Control Components

The Plant control system provides a distributed digital supervisory control and monitor system. The system design distributes the physical and functional elements of each subsystem between the field and a central Plant control center, providing independent subsystem control for manual plant operation and coordinated supervisory control for automated and unattended Plant operation. Single control loop integrity is maintained throughout the Plant which prevents central control hardware failures from affecting the stability of the individual controllers. The controller and sensor monitoring equipment is located in the field in the vicinity of the subsystem equipment. The controller and monitoring equipment is linked to a central operator and supervisory control station by a single digital serial signal transmission cable. This arrangement reduces the length and cost of individual controller and sensor signal wiring and provides a near electrical noise immune signal path from the field control electronics to the central control console electronics.

A block diagram of the baseline control system for the EE No. 1 programs is shown in Figure 4.8-7.

This configuration adopts automated control functions for each of the programs (4.5-year, 6.5-year, and commercial) through the addition of field modules that replace local field indicators and control and by expanding the software

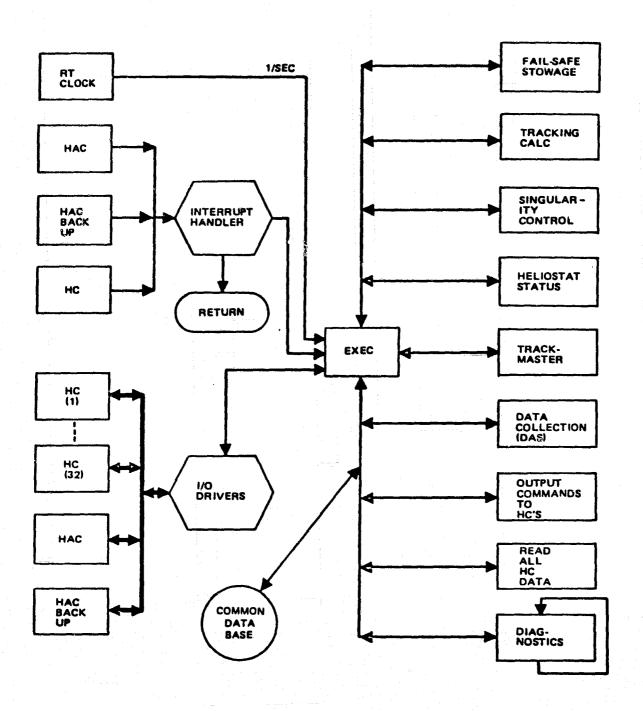


Figure 4.8-6. Collector Control Software Architecture

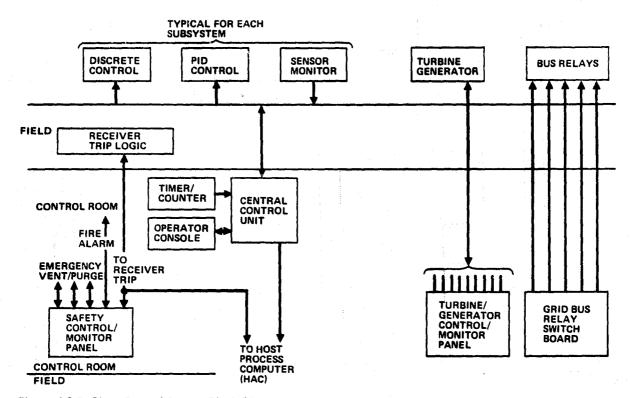


Figure 4.8-7. Plant Control System Block Diagram

applications in the host process computer. The commercial system, which operates automatically and in an unattended mode, is configured with a redundant set of hardware and an automatic fail over capability at the host computer level. An overview showing the relationship of system control configurations for each of the programs is shown in Figure 4.8-8. The degree of automation applied to each program is predicated on the development time available for each of the programs. The 3.5-year program provides the basic tools for automation with limited automation implemented. However, this program has the advantage of obtaining the operating experience of the Plant using extensive manual control and developing the automated control logic for each subsystem from this experience.

#### 4.8.1.4 Supervisory Control Hardware

The HAC processor hardware, diagrammed in Figure 4.8-3 shares the functions of collector Supervisory Control and Plant Supervisory and Automated Control functions. The computer system hardware and software architecture supports a real time operating system that provides multitasking of collector and plant control functions with memory partitioning and protection features. Analysis

SUBSYSTEM	3.5-YEAR SYSTEM	4.5-YEAR SYSTEM	6.5-YEAR SYSTEM	COMMERCIAL	
COLLECTOR/ CONCENTRATOR	THREE ELEMENT LIKE 10 mW	COMBINED INTO		•	
COLLECTOR/ RECEIVER		WARMUP AND     SHUT DOWN     AUTOMATED	-	= -	
ENERGY TRANSPORT	CONTROL AND MONITOR FROM PLANT CONTROL			REDUNDANT CONTROL AND	
ENERGY STORAGE	TRANSITIONS TO     STEADY STATES	Williams of the state of the st		MONITORING SYSTEMS  ALL SYSTEMS  AUTOMATED	
POWER CONVERSION/ PRIMARY LOOPS	AUTOMATED	WARMUP AND SHUT DOWN AUTOMATED	TURBINE STARTUP     SHUT DOWN     AUTOMATED	AUTOMATED	
POWER CONVERSION/ BOP - FACILITY	MANUAL MONITOR AND CONTROL	-	PARTIAL CHEMICAL     TREATMENT     AUTOMATED     ALL OTHER SYSTEMS     FULLY AUTOMATED	FULL CHEMICAL     TREATMENT     AUTOMATED	

Figure 4.8-8. Plant Control System Configurations

results show that the hardware selected, dual MODCOMP Model 7810 computers with peripherals, provides the required throughput performance with an adequate margin to accommodate both functions.

The dual computer central processing units are supported by moving head disc mass storage devices with removable disc cartridges capable of storing up to 2.6 megabytes of program code and plant status data.

An operator console is provided for each computer. Each console consists of an alphanumeric keyboard integral with a black and white CRT display, mounted in the control console.

A printing device is also connected to each computer and serves to log and report plant status in hardcopy form. These devices are free standing.

The input and output interface between the computer and the plant control hardware consists of a serial bi-directional four wire communications channel.



This channel is an available channel of a set of sixteen multiplexed serial channel interfaces that service the collectors. The signal and control interface conforms to RS232-C standards and operates up to 9600 baud.

## 4.8.1.5 Subsystem Control Hardware

Subsystem control hardware allows the operator to control the plant subsystems from a central control point without the host computer in the loop. This hardware, called the Central Control Unit (CCU), and located in the control console, combines sequential, timing, counting, data handling, interlock, and mathematic function capabilities for controlling the individual element controllers of each subsystem.

The CCU interfaces with the host process computer (HAC) for supervisory control and monitoring command instruction, with the operator for manual control and monitoring command instruction and with the subsystem field controllers for individual control element monitoring and control.

The subsystem control equipment is part of a programmable control system that is integral with the field control and monitoring elements and is provided by the Texas Instruments Corporation, Model PM 550 Hardware. A block diagram of the plant subsystem control hardware is shown in Figure 4.8-9.

The dual microprocessor design of the CCU provides the capability for solving three mode control algorithms (proportional, integral, derivative) and perform sequential logic operations simultaneously. The CCU also consists of 7K words of memory for programming special algorithms, storing variables (i.e., set points, alarms, controller gains and bias functions, engineering unit conversions, etc.).

A timer/counter unit is connected to the CCU. This device provides display and adjustment of individual and programmable timers and counters located in the CCU assigned to control and monitoring functions.

An operator console connected to the CCU enables the user to program sequential logic, timing, counting, math functions and three mode loop control functions

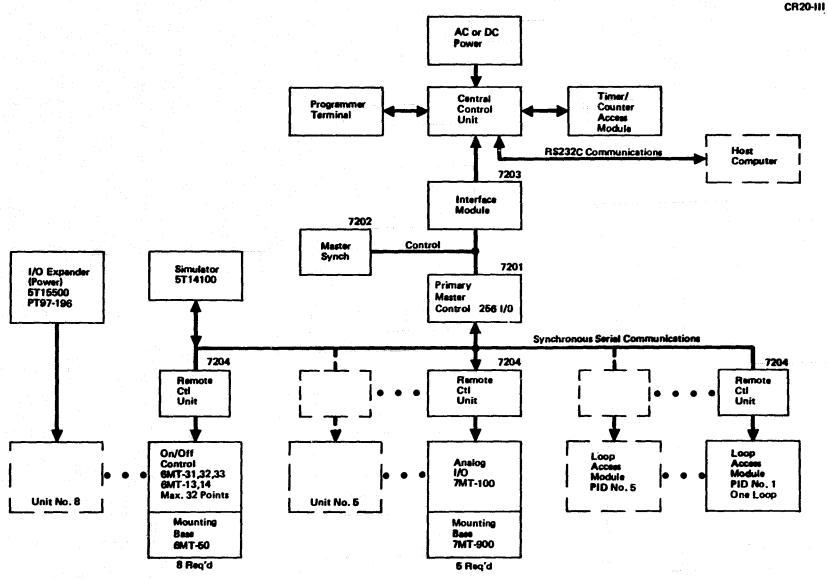


Figure 4.8-9. Block Diagram Plant Subsystem Control Hardware (TI-PM550)

(PID) into the CCU. This programming is accomplished using an English language prompting feature, utilizing question and answer operator interface protocols. The terminal incorporates a visual display to monitor messages and data. A picture of the operator keyboard/display with function descriptions is shown in Figure 4.8-10.

The input and output interface between the Central Control Unit and the element control units in the field provides for control up to 2,500 feet from the central control console using a single cable comprised of three individually shielded, twisted pairs of wire (Belden No. 8777, or equivalent). This I/O interface, provided by Control Junctions, Inc., Model 7200 RPM system, provides time division multiplexing communications for a control sequence (transmit and receive) every 8.33 microseconds. A typical control-communications configuration using this equipment is illustrated in Figure 4.8-11.

#### 4.8.1.6 Element Control/Monitor Hardware

The element control and monitor hardware consists of: (1) discrete input and output modules to control and monitor "on-off" functions (i.e., limit switches, solenoids, starters, contactors, etc.); (2) analog input and output modules to control and monitor analog devices (valve positioners, flow, pressure, temperature, etc.); and (3) loop access modules for the monitor and control of three mode type control functions (variable control valves, blowers, motors, etc.). These modules are an integral part of the Texas Instruments PM 550 system, tied to the CCU through the serial digital cable and the remote multiplexing system (7200 RPM system). The field control and monitor modules are strategically located close to the subsystem equipment in clusters that maintain short analog signal wire runs and efficiently utilize the control equipment capacities. These units are rack mounted in Nema Environmental Enclosures and require no special temperature environmental conditioning for the range between 0 to 60°C.

The discrete input and output modules change AC or DC input signals to logic levels acceptable by the CCU and change logic levels from the CCU to output signals that drive loads. The input and output modules accept or output voltages ranging from 17 to 260 VAC and 4 to 28 VDC. A single input/output functions are handled by this hardware.



#### CR20-III

Displays instructions and memory location or prompting message. Selects master control relay function. — Selects timer function. —

Selects counter function

Store key used to start new ladder line.

Selects external input. -

Defines memory locations for variable data.

Power flow lamp used as troubleshooting tool.

Used to locate an \_\_\_\_\_ instruction in memory.

Selects external output.

Used to compare the magnitude of two numbers.

Defines memory locations for constant data.

Pressed to define a PID loop prompting sequence.

Move data from one location in memory to another.

Selects up to 512 — internal control relays.

Defines 7MT I/O module location.

End of scan—used to — reduce system scan time.

Special function—used with digit key to call up one of the available

special functions.

Auxiliary function—used with digit keys to call up auxiliary function.

Used to respond to prompting message.



Used to generate internal (CR) or external (Y) outputs.

 Inverts logical status of input/output elements.

 Used to enter parallel 6MT I/O elements.

Used to enter series
 6MT I/O elements.

- Selects jump instruction.

 Inserts new elements between those previously entered and moves them ahead one location.

 Deletes an element and relocates subsequent instructions to fill blank space.

 Pressed each time an entry is to be made to the central control unit.

> Clears display and retains location.

Advances to next location and readies programmer for new entry.

Calls out previous instruction number.

Clears programmer display.
 Shows "ready" condition.

When pressed will display contents of selected memory location.

---- Pressed for math operations.

Digit keys 0 through 9 select all numerical identifying numbers.

Figure 4.8-10. Operator Keyboard/Display

4-162

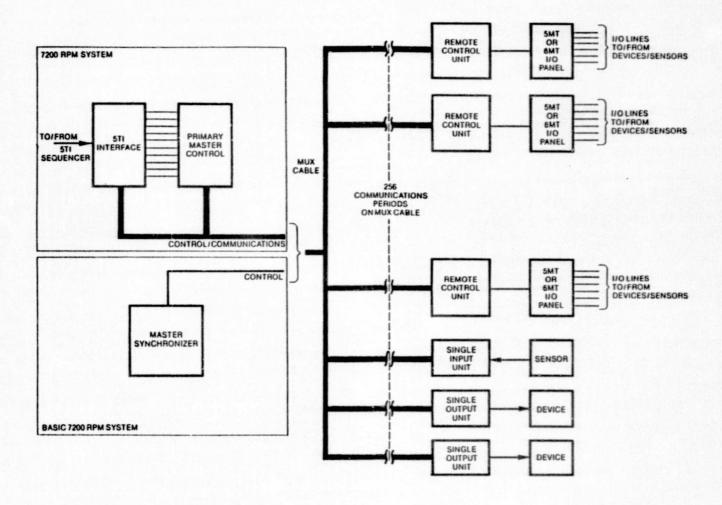


Figure 4.8-11. Typical Control-Communications Configuration

The analog input and output modules can be used with either a current or voltage device. O to 5 VDC or 4 to 20 MA analog inputs are digitized to 12 bits resolution, while analog outputs are converted from 10 bits resolution to analog voltages ranging from 0 to 10 VFS or 4 to 20 MA. A maximum of 256 inputs and 256 outputs can be accommodated with these modules.

The loop access module (LAM) provides monitoring and control of the PID functions in the plant. This unit programs the output to the controlled device, controls the device to the given set point, tests for alarm conditions, and measures the deviation or bias of the control loop. This module can be programmed and operated either from the CCU remotely, or if convenient for test or checkout locally from a built in control panel and display. A maximum of eight LAM devices can be configured in the system.

A simulator interfaces through the serial digital communications cable to the CCU for diagnostic testing and troubleshooting. This unit, capable of simulating 32 inputs and outputs, is used to isolate problems in the program logic, I/O modules, or interconnect cables.

#### 4.8.1.7 Plant Process Control Functions

The distributed plant process control design approach is consistent with the approach applied to the collectors. The distribution of control and monitoring responsibilities of the plant control system are divided into the following functional categories:

- Supervisory and coordinated control central control directory for plant status monitoring and automatic controlling functions.
- Manual subsystem control central control directory for the manual control and monitoring of each subsystem.
- Element control control and monitoring directory of individually controlled elements of each subsystem.

The functional plant control directory assigned to the hardware components of plant control is illustrated in Figure 4.8-12.



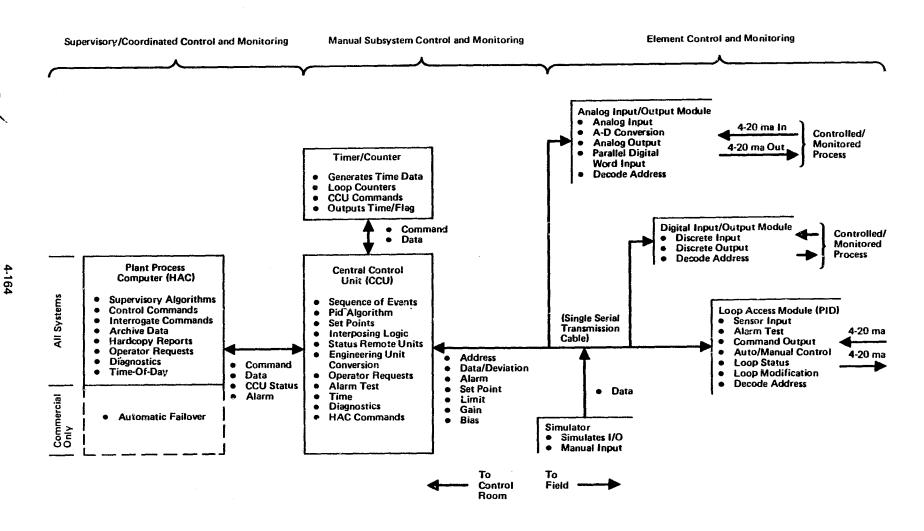


Figure 4.8-12. Control System Description Plant Control Functions

The supervisory coordinated control of the plant subsystems residing in the HAC utilizes a software executive, and scheduler and data base architecture shown in Figure 4.8-13. The applications software modules execute on a priority time schedule basis that is modified and arranged by executive functions and the operator. Applications software tasks execute to completion and "drop through" to the next task in the priority change or suspend execution if a higher priority task, under interrupt or operator control, is designated to execute. Upon completion of the higher priority task, the suspended task resumes execution.

The round-robin plant supervisory control strategy will be designed to allow on-line diagnostics of the computer system hardware to run during idle time.

## 4.8.2 Operational Characteristics

The plant control subsystem covers all aspects of the total system including all subsystems. Operational characteristics of the total system are covered in Section 4.1.2 of this volume and will not be repeated in this section.

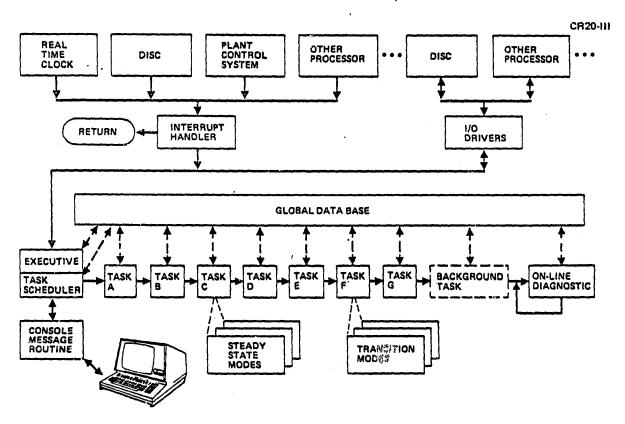


Figure 4.8-13. Plant Control Design Details Plant Control Software Archtecture

#### 4.9 SECTION 4 REFERENCES

- 4-1 "Evaluation of Optical Radiation Hazards," D. H. Slimey and B.C. Freasier, Applied Optics, Jan. 1973, Vol. 12, No. 1.
- 4-2 "A Study of Optical Radiation Hazards Associated with a Solar Power Facility Proposal," W. T. Hain and D. H. Slimey, August 1976.
- 4-3 "Eye Hazard and Glint Evaluation for the 5 MW Solar Thermal Test Facility," T. M. Brumleve, SAND76-SAND-76-8022. Sandia Laboratories.
- 4-4 "Solar Central Receiver Prototype Heliostat, CDRL Item B.d., Final Technical Report," C. R. Easton, MDC Report No. G7399, August 1978.

# Section 5 FABRICATION AND INSTALLATION CHARACTERISTICS

Production and procurement philosophy for an experimental plant is to employ commercially available items to the extent compatible with the system design. Competitive procurement will be employed through established MDAC procedures for issuing Request for Bid and Request for Proposal to qualified suppliers. No economy of scale will be available for the experimental plant, except for the concentrator heliostats. Our plan is to acquire heliostat hardware and components from the MDAC production line which will be producing heliostats for other programs.

The absorber has a unique design and will be procured from Rocketdyne, the subcontractor. Manufacture of the absorber will be accomplished by a supplier using standard and proven techniques for coiling large-diameter tubing.

Within transportation constraints, the components used in the fabrication of a subsystem will be assembled into the subsystem at the originating manufacturing facility. Prior to shipment, each subsystem will undergo testing to the level practical. Assembly and test beyond this level will take place at site.

During production and procurement of the experimental plant hardware, MDAC and their qualified suppliers will conform to the following manufacturing practices:

A. The level of workmanship will conform to practices defined in the codes, standards, and specifications applicable to the selected site and the using utility. Where specific skill levels or certifications are required, current certification status will be maintained. Where skill levels or details of workmanship are not specified, the work will be accomplished in accordance with the level of quality currently in use in the construction, fabrication, and assembly of



- commercial power plants. All work will be finished a manner precluding hazards to operating and maintenance personnel.
- B. Standard materials and processes will be employed. Highly stressed components and unusual material will be avoided. As far as practical, off-the-shelf components used in industry will be employed. Materials and components susceptible to environmental deterioration will be protected with a suitable coating or protective layer.
- C. All deliverable end items will be labeled with a permanent nameplate listing manufacturer, part number, change letter, serial number, and data of manufacture. All access doors to maintainable items will be labeled to show equipment installed in that area and safety precautions or special considerations to be observed during servicing.
- D. Conformance of hardware to the design and to the applicable detail specifications will be verified as system elements are manufactured and as the system is integrated. For purposes of plant acceptance, this verification of conformance includes proof by assembly, the examination of inspection and test records, and subsystem and system demonstration.
- E. Formal design qualifications will incorporate satisfactory completion of all required tests, including those specified for subsystems and completion of all other verifications required including integrated system demonstration tests.
- F. The quality assurance concept provides for hardware verification at the highest assembly level. Proof of hardware acceptability is thus confirmed by performance rather than by detailed inspection. The quality assurance concept is based on the application of the following preventive controls:
  - 1. Receiving inspection of incoming material prevents accepting large quantities of unusable parts or materials.
  - 2. Manufacturing inspection guards against producing quantities of unusable parts.
  - 3. Finished-article testing minimizes field rework of hardware.



Descriptions in the following paragraphs are the baseline for the Engineering Experiment No. 1, 3.5-year program. Variations applicable to the 4.5-year and 6.5-year programs are defined or noted as required.

#### 5.1 PROCUREMENT, MANUFACTURING, AND ASSEMBLY

Standard materials and off-the-shelf components will be used in subassemblies to the maximum extent possible. All parts which are not commercially available will be defined, documented, and fabricated. Commercially available items will not be proprietary.

All elements will be assembled and checked at an off-site manufacturing facility. Subassemblies will then be shipped to the site for final assembly in the field.

# 5.1.1 Collector Subsystem

The collector subsystem will be comprised of the concentrator assembly, the receiver assembly, and the tower assembly.

# 5.1.1.1 Concentrator Assembly

Subassemblies for heliostats for the 3.5-year program will be obtained from an existing high-rate production assembly line designated for the DOE 10 MWe plant. Minor modifications reflecting design improvements will be implemented in the manufacturing processes. This flexibility is guaranteed as a result of MDAC's dedicated commitment to the solar energy field.

Four subassemblies that will comprise a heliostat are reflector panel, drive unit, pedestal, and control and electronics. Manufacturing processes for the four subassemblies of both the pilot plant and second generation heliostats are as follows.

- A. Reflector Panel 3.5-Year Program--The reflector panel for the 3.5year program consists of six mirror modules. Each mirror module (Figure 5-1) is a composite structure consisting of:
  - 1. The reflecting surface is a 3.2-mm (0.125-in) thick second surface mirror.



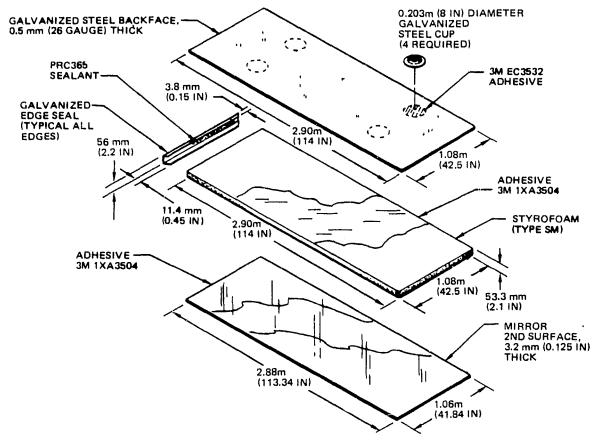


Figure 5-1. Mirror Module Components—Exploded View Showing Steel, Foam Glass Edge Seal, and Adhesives

- 2. The core is a piece of styrofoam which is 2.9 m (114 in) by 1.08 m (42.5 in) by 53.3 mm (2.1 in).
- 3. The backface is galvanized steel sheet metal 0.5 mm (0.022-in) thick.
- 4. The four galvanized attach cups are die-formed and have a pressed nut in the center.
- 5. The edge seal is roll-formed galvanized steel.

The mirror module interface requires precise positioning of the attach points with respect to the mirror surface. Fabrication capability has been specifically designed to meet this important requirement. Some of the more important factors in this process are:

- Galvanized steel backing plates are purchased cut to size. Grit blasting of adhesive interface areas for bonding will be done before assembly.
- Styrofoam is passed through a special sander which removes material from both top and bottom surfaces simultaneously to achieve the necessary parallelism. The edges are then sawed to size.



- Galvanized steel cups are blanked and formed out of coil stock. A press nut is then installed. Prior to assembly, adhesive interface areas will be grit blasted for bonding.
- Galvanized steel edge seals will be purchased. Adhesive interface areas will be grit blasted for bonding prior to assembly.
- Mirrors are purchased and only required a "wipe" cleaning operation prior to assembly.

After panel assembly verification, the completed mirror module is loaded into a special stacking, shipping unit that will accommodate the mirrors for shipment.

- B. Reflector Panel 4.5-Year and 6.5-Year Programs--The reflector panel for the heliostat consists of six mirror modules and support structure. Each mirror module will be fabricated as follows (Figure 5-2):
  - 1. Adhesive is applied to the second surface mirrored glass.
  - 2. The cleaned float glass back lite is positioned on the mirrored glass, and rolled to ensure a good adhesive bond.

    Six mirror modules are positioned on a bonding table, which is curved to

the proper radius for each module. Gravity causes modules to slightly bend 2.5 mm to the proper shape.

Adhesive is applied to the back of each mirror module in preparation for bonding to the support structure. A previously assembled support structure is lowered onto the mirror modules and aligned for interface to the main beam with respect to the mirror surface. Each module is stiffened and bonded to two hat-section stringers which are part of the support structure. Twelve hat-section stringers are secured to two cross beams which provide the main support for the entire reflector panel. Two diagonal beams secured to the cross beams provide additional support.

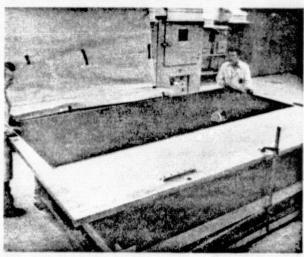
Reflector panels will be easily transported.

Mirror module and support structure production techniques will be modified due to cost considerations and design changes for Small Power Systems.

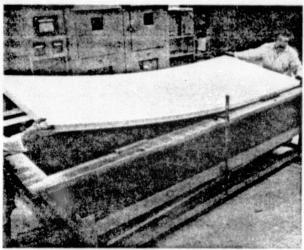




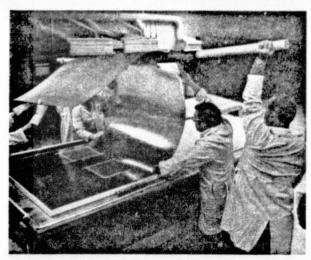
SPRAY ADHESIVE ON MIRROR BACK (AND GALVANIZED BACK SHEET)



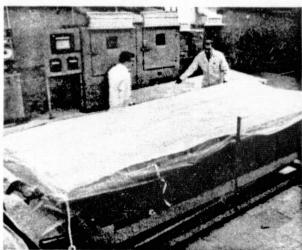
POSITION SPRAYED MIRROR ON CURVED TOOL PLATE



POSITION STYROFOAM AGAINST FIXTURE LOCATORS ON TOP OF SPRAYED MIRROR

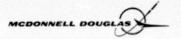


POSITION SPRAYED GALVANIZED BACK PLATE AGAINST FIXTURE LOCATIONS ON TOP OF FOAM



VACUUM BAG AND CURE

Figure 5-2. Mirror Module Assembly



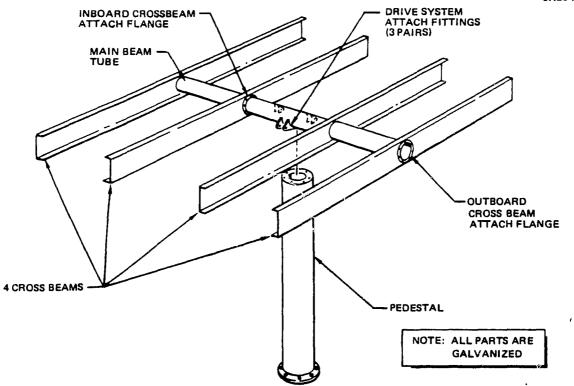


Figure 5-3. Support Structure and Pedestal

C. Pedestal - 3.5-Year Program--The structure and pedestal which support the mirror modules are shown in Figure 5-3. The cups on each group of six mirror modules are bolted to two cross beams. These galvanized beams are rolled channels of 13-gage galvanized steel. They measure 0.42 m (16.5 in) in height with a flange width of 63.5 mm (2.5 in) and a return lip of 15.9 mm (0.625 in).

The tubular main beam connects the two groups of six mirror modules together, and ties the reflector to the drive system at the top of the pedestal. The main beam transfers all the wind and dead weight loads from the reflector through the drive unit to the pedestal. It is 5.40 m (212.5 in) long, with a 0.356-m (14-in) outer diameter, and is formed of 12-gage steel sheet and hot-dip galvanized after fabrication. Flanges are welded to the tube and provide for the attachments of the four cross beams. In the slot between the two six-panel groups, the main beam has three pairs of steel lugs welded to it. Two pairs of these lugs serve as the support for the elevation hinge line. They are attached to the drive housing at the top of the pedestal with two pins. The other pair of lugs is the attachment for the stowage jack.

The support for the heliostat is provided by the pedestal. It is 2.74 m (108 in) high to provide ground clearance. It is fabricated of 0.508-m (20-in) diameter spiral-welded steel pipe from a 12-gage steel sheet, hot-dip galvanized after welding. A flange with eight attachment holes is welded to the bottom of the pedestal to provide attachment to the foundation through anchor bolts and double nuts. An internal flange with tapped holes, welded to the top of the pedestal, serves as the attachment for the drive system.

- D. Pedestal 4.5-Year and 6.5-Year Programs--The pedestal will be fabricated from a 0.61-m (24-in) diameter tube, 3.14 m (123.5 in) long. The lower 1.12-m (44-in) length of the tube will have a slight flare to accommodate the slip joint on the foundation. Hydroforming equipment similar to that used by American Hydroforming will be utilized to make the flared end. A Recessed junction box will be located 1.37 m (4.5 ft) from the bottom of the pedestal. A draw-pressed cap, made from 9.53-mm (0.375-in) low carbon steel, will be fusion-welded to the top of the pedestal.
- E. Drive Unit 3.5-Year Program--The drive system configuration shown in Figure 5-4 is made up of a harmonic azimuth drive unit, a screw jack tracking drive unit, and a screw jack stowage drive unit. The drive assembly housing casting, drag link casting, worm gear housing casting, drive shafts, and bearing retainers and miscellaneous components will be machined at MDAC. The remainder of the drive system components will be received from suppliers.

The drive assembly components machining will be accomplished using the most cost effective balance of conventional and NC machining equipment to satisfy the 500- to 2,500-unit requirement for the Pilot Plant.

The highlights of the assembly operations are:

The mating surfaces of the flex spline and drive housing receive the primary shear loads in the azimuth unit. In order to pull these two surfaces together and meet the shear requirements at a low cost, huckbolts were selected as fasteners. Installation of the huckbolt requires a uniform, aligned bore through the flex spline

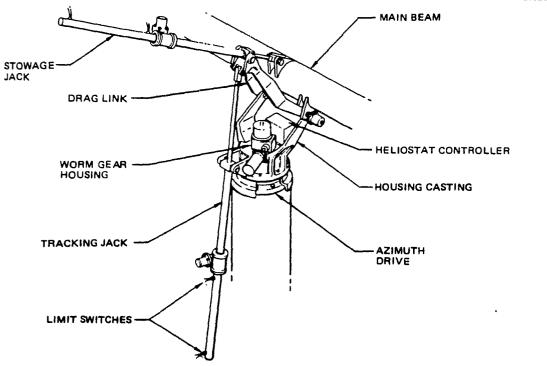


Figure 5-4. Drive System Assembly

and drive housing. The flex spline will be purchased with undersize mounting holes. The flex spline will be located on the drive housing and the two components will be drilled and reamed to size in a 12-hole pattern through the flex spline.

- 2. The location of the harmonic shaft and bearing assembly in the drive housing is maintained by a special assembly fixture. The drive housing is held in an inverted position and the drive shaft and bearing assembly are pressed into the drive housing until the shaft bottoms on the tool land.
- 3. The engagement of the flex spline teeth with the circular spline teeth occurs as the wave generator is positioned down into the flex spline. A magnetic chuck will be used to position the wave generator. After insertion of the wave generator, correct tooth engagement of the flex spline and circular spline is checked by using a feeler gage. The teeth at each end of the minor axis of

- the flex spline will clear the circular spline teeth by an equal distance when proper engagement is made.
- 4. Alignment of the worm gear with the worm shaft is essential for efficient operation and long life. Using a special tool the dimension from the centerline of the worm shaft to the inner race of the harmonic shaft bearing will be measured. The height of the worm gear (based to centerline of gear) will be measured. The difference between the two dimensions represents the shim requirement between the base of the worm gear and the inner race of the harmonic shaft bearing.
- 5. The drive final assembly is the last operation performed. This consists of the assembly of the drag link, jack screws, motors, encoders, limit switches, and associated wiring. A functional check will be made of the assembly.
- F. Drive Unit 4.5-Year and 6.5-Year Programs (Figure 5-5)--The drive unit consists of a drag link, azimuth drive assembly, and actuators. After assembly and functional check, the unit will be mated to the pedestal and center support segment. The HC is then installed at the top of the drive unit housing. Electrical connections will be completed, and protective corners installed on the reflector panels.

A final checkout of the completed assembly will include a production acceptance test to insure the integrity of the elevation and azimuth drives and the electronics. The completed assembly is then shipped to the site for final assembly in the field.

Variations to the drive unit for Small Power Plant heliostats will occur as the elevation components are assembled onto the azimuth drive assembly. The drag link will be positioned so that the pivot points are in line. The drag drag link will be centered and secured in line with the azimuth drive. The center segment of the main beam will be lowered until the flanges are aligned with the pivot points of the drag link and housing, and then secured to the drive unit with bolts. The assembled center segment and drive unit will be hoisted and lowered onto the pedestal

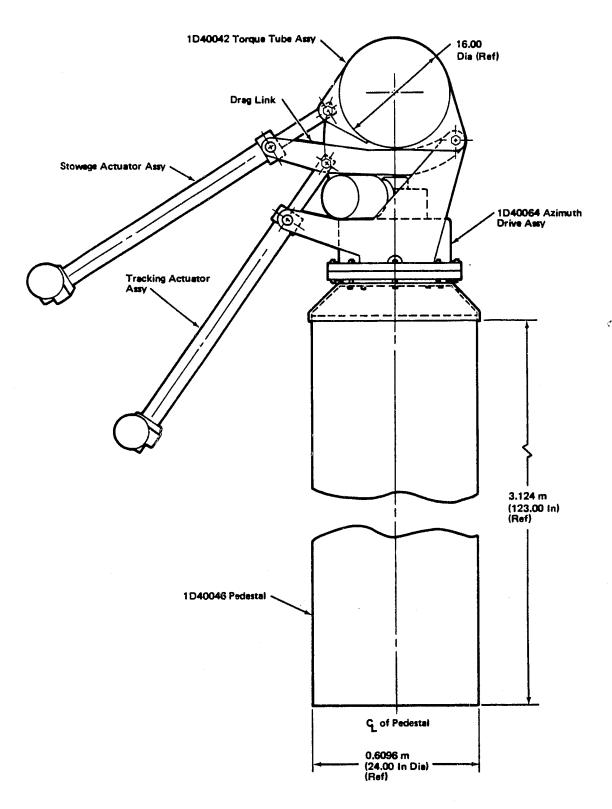


Figure 5-5. Drive Unit



(Figure 5-6). Guide pins will be used to align the hole pattern of the spline section of the drive unit with the top of the pedestal. When guide pins are removed, the joint will be secured by bolts through the cap into the circular spline. Electrical installations will be completed and the drive unit/pedestal will be shipped to the site.

G. Control and Electronics--Control and electronics for the concentrator assembly (3.5-year progrm) will consist of 217 heliostat controllers (HC) and motor/sensors, 32 heliostat field controllers (HFC), and one heliostat array controller (HAC).

Although manufacturing techniques are described for the HC, similar techniques will be utilized for production of HFC's and HAC.

The HC will consist of three printed wiring boards (PWB) and a power supply installed in a J-box. An EMI shield is installed to isolate the motor control PWB and power supply from other components. The J-box will have a standard edge-sealed cover.

CR20-III

Figure 5-6. Final Assembly Joining Area Drive Unit to Pedestal

PWBs and components will be manufactured in accordance with electrical/electronic industry accepted production techniques and reliability standards. Drive motors, encoders, and limits switches will be of conventional design.

A nonvolatile memory unti will be added to HC's for Small Power Systems. Absolute encoders will be deleted.

# 5.1.1.2 Tower Assembly

Manufacture of tower assembly components will be accomplished by local steel fabricators in accordance with current standards for the industry. Tower members will be cut to length, punched, and piece-marked for subsequent delivery and assembly on-site.

#### 5.1.1.3 Absorber Fabrication

A manufacturing technique which requires only existing tooling has been suggested by several manufacturing firms. In this method, shaped rollers are oriented so as to force the tubing into the desired curve as it is passed through the rollers. This method is much less costly than the mandrel technique. Standard lengths of seamless tubing are buttwelded together to form approximately 200-ft lengths. Four of these are laid parallel and fed into a standard roll-bending machine equipped to handle four tubes at once. The rollers are oriented so as to force the tubing into the desired curve as it is passed through the rollers.

A uniform, automatically welded, buttweld will be required where the standard lengths of tubing are joined together. This will be a gas, tungsten-arc weld. The spiral weld placed between the tubes will be a MIG weld (GMAW). The welder will be code-approved and all welds will be x-Rayed. The finished absorber will be Boiler Code stamped. The applicable code is Section 1 of the Boiler Code.



The absorber will be constructed in two separate sections: an aperture section and an apex section. This is done for the following reasons:

- A. The fabrication step should be less costly since handling and supporting the partly completed structure will be simplified.
- B. The shipping of the two sections separately is simplified as compared to a single section absorber.
- C. It is anticipated that the more advanced absorber designs will eventually permit the use of two different materials: a cheaper, low-temperature material for the aperture portion and a more expensive, high-temperature material for the apex portion. The transition from one material to the other can conveniently be made to take place at the juncture between the two sections.
- D. It may prove advantageous to use a different technique to fabricate the aperture section from the apex section. The two-section concept allows automatically for this design freedom.

A conceptual sketch of the way the joining means can be accomplished is shown in Figure 5-7.

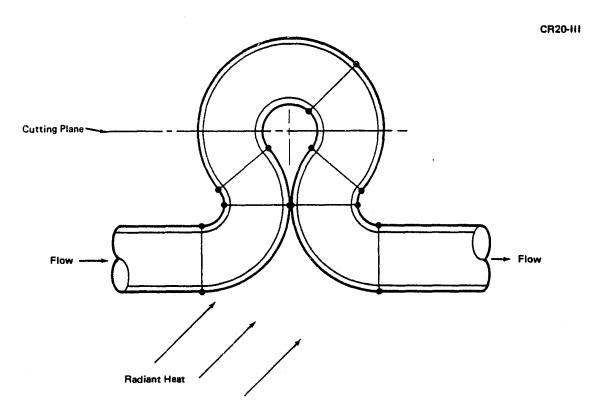


Figure 5-7. Omega Shaped Joint at Junction Between Two Absorber Sections



The omega-shaped turn in the tubing is constructed of standard butt-welded pipe fittings. The two sections are welded together in the factory and then cut apart just before shipping. This will ensure that the parts will match when they have to be welded together in the field at the base of the tower. The portion cut away will be a  $180^{\circ}$  bend and is also the point at which the transition can take place from one material to another. This an ideal point for this transition since no thermal gradient will exist across the tubing because it is not exposed to the solar energy, and the entire joint will assume the temperature of the bulk fluid flowing through it.

Each of the four parallel tubes has one of these omega couplings in it at the transition point, and they are spaced  $90^{\circ}$  apart in order to preserve the flow symmetry.

At a point about 2 ft below the apex at the top of the manifold, the four parallel tubes terminate and are welded into a single structure called the apex manifold. It is considered more economical to construct and weld this manifold into place than it is to continue the four tubes into a tighter and tighter spiral until they reach the apex of the cone. In addition, it is problematical whether or not the tubes can be bent so tightly as to achieve an adequately closed surface if the latter construction procedure were to be followed.

The inside of the manifold is a flat sheet formed into the shape of a cone and welded together. A fence approximately 1 in high and running spirally around the cone to the apex is then welded to the surfact of the cone. The spiraling fence has a pitch of seven in which corresponds to the width occupied by four of the standard spiralling tubes in parallel. A second fence midway between the above spirals is added to limit deflection of the flat sides due to pressure. The resulting flow velocity of the cooling fluid is identical to that in the four parallel tubes. The four parallel tube ends are then welded into the manifold and closure of the passage is completed by

welding a closing plate spiralling around the outside with the seams welded on top of the fences.

The absorber will be shipped to the tower site in two sections. The aperture section will be laid with the aperture side downward on the ground. The apex section is then hoisted above it and lowered carefully onto the aperture section. The four omega couplings which connect the tubing between the two sections are then welded into place, and the welds are x-rayed with a portable x-ray machine. The two halves of the supporting strap are then welded together. The special sections of insulation which are built to cover the absorber are then put into place. The absorber is then ready to be fastened into the receiver structure and mounted on the tower.

## 5.1.2 Energy Transport Subsystem

All lines, pumps, and valves will be fabricated using standard, proven manufacturing processes. Components requiring long-lead times are submerged pumps and drag valves. Pumps will be flow-tested with water at the factory.

# 5.1.3 Energy Storage Subsystem

All tanks will be shop-fabricated using standard, proven manufacturing processes. Manifolds in the dual media thermocline tank will be installed during construction of tank. Tanks will be hydro-tested at the factory.

# 5.1.4 Power Conversion Subsystem

Manufacturing planning for the Small Power System plant will be based on small production runs (1 to 10 units) using standard off-the-shelf equipment where-ever possible. Factory assembly, testing, and skid-mounting will be employed whenever possible to minimize assembly at the site.

Turbine, generator, steam generator, and all other major components will be tested at the factory before shipment to the site.



ETI has developed highly automated manufacturing techniques for the ROF turbine which make use of state-of-the-art computer controlled machine tools. Recent investments in this advanced technology give ETI the capability to perform the entire processing of the turbine blade profiles from design to hardware in-house. Drawings for the turbine blade aerodynamic profiles are converted into control tapes on a specialized computer. These tapes drive a wire electrical discharge machine, which duplicates the profile drawings in steel with extreme accuracy. Use of this technique is possible because of the two-dimensional blade shapes in a radial turbine (axial turbine blades are three dimensional). Labor and tooling requirements with the manufacturing process are minimal.

Because all blade rows are on a single disc, rotor and stator seal surfaces can each be machined in a single setup. Very tight tolerances on stage tip clearances can be maintained yielding low leakage—a major factor in obtaining high turbine efficiency. The process of machining the interstage shaft seals can be accomplished at low cost on a numerically controlled lathe. Another advantage of the radial design is that the rotor/stator clearance can be varied without need for modification. This permits break—in of the unit at larger clearance, lessening developmental risk.

The speed reducer selected by ETI is built by Western Gear to meet the requirements established by the American Gear Manufacturers Association and the American Petroleum Institute. Rigid production quality control standards are maintained to insure long term reliability.

Gearing is generated in a continuous process by precision hobbing machines. Precision shaving improves involute profile, lead and finish and provides optimum tooth contact. Housings are designed with the aid of computer generated finite element models to provide stable support for the gearing.

The gearbox will be given a running test at the plant for performance verification before being shipped to ETI for coupling with the ROF turbine.

## 5.1.5 Plant Control Subsystem

The plant control subsystem utilizes two types of control equipment:

- Control console for operation and control of concentrator assembly
- Valves, motors, and components for power plant processes

All hardware will off-the-shelf equipment. Availability and lead time will not present problems.

The control console will be assembled and checked out in the factory. New software will be integrated and debugged during checkout.

Specially designed checkout equipment will not be required. Standard electronic laboratory test equipment and hand tools will be sufficient.

#### 5.2 TRANSPORTATION AND HANDLING

This section contains a description of the approach taken for transporting all components of the Experimental Power System to site.

Due to the fact that site locations were not known with certainty, and since truck transportation is more flexible and economical than rail transportation (particularly when small production quantities are considered), all transportation requirements were formulated with respect to a standard truck load baseline. Standard truckloads are formed from components assembled at the plant to be shipped to site. Certain components which will be sent directly from manufacturer to site are assumed to use commercial shipping channels. Standard loads and outside items (with respect to trucks) are described in Table 5-1. Standard crating, cushioning, and/or bracing can be expected for all these items.

#### 5.3 PLANT CONSTRUCTION AND EQUIPMENT INSTALLATION

Construction of experimental plant facilities will employ a conventional building trades approach. Similarly, installation of site operating equipment will be accomplished using mostly trade union labor, and conventional support equipment, cranes, trucks, etc.



TABLE 5-1. Transportation Data: Major Items--Standard Truck Loads

Item	Quantity per site	Truck loads per site		
I.	Standard Truck Loads			
Mirror Modules/Cross member/ Outrigger Main Beam Assembly				
3.5-year 4.5-year 6.5-year Commercial	434 342 278 266	55 43 34 34		
Pedestal/Drive Main Beam Assembly				
3.5-year 4.5-year 6.5-year Commercial	217 171 139 133	15 12 10 9		
Cables and Connectors (Power and Control)		1		
Receiver Tower Steel				
Vertical Horizontal Diagonal	52 } 52 } 104 }	1		
Energy Transport Feedpump	2	1		
Trace heat bundles and insulation sections		1		
Valves	29)			
Piping	<b></b> }	commercial ship.		
Turbine/Generator/Condensor	1	1		
Energy Storage Subsystem				
Valves Regulators Sensors Heaters	9 2 20 2	commercial ship.		
Deaerator PGS Pumps PGS Heaters	1 8 4	l commercial ship.		

TABLE 5-1. Transportation Data: Major Items--Standard Truck Loads (Continued)

Item	Quantity per site	Truck loads per site		
Steam Generator Chemical Feed System	1	1		
Demineralizer	1	1		
PGS Valves PGS Sensors and Meters Piping	187) 42} 	commercial ship.		
Boiler Chemical Feed System PCS Monitor Panel	1 1	1		
PCS Consoles	5 (6 for Commercial)	1		

# II. Outsize Items\*

		Requires			
Item	Dimensions	Critical truck Dimension	Routine issue permit	Special permit	Route survey
Absorber:					
3.5 year 4.5 year	10.5 ft W x 10.5 ft H**	width height width	X X X		
6.5 year Commercial	11.80 ft W x 11.80 ft H 10.58 ft W x 10.58 ft H	height width width	X X X		
TSS Tanks:					
3.5 year Hot Cold 4.5 year Hot Cold 6.5 year and comm	12 ft D x 37 ft L 12 ft D x 33.3 ft L 12 ft D x 28.9 ft L 12 ft D x 26.4 ft L 10.6 ft D x 20.13 ft L	width width width width width	X X X X X		
Cooling Tower***	12 ft x 18 ft x 23 ft	width height			

<sup>\* -</sup> Within southwestern states

NOTE: When height is a critical dimension, a special low bed truck is required.

<sup>\*\* -</sup> Maximum Dimensions. Absorber in two pieces.

<sup>\*\*\* -</sup> Must be partially disassembled

Analysis of the system and subsystem design has revealed no abnormal construction or installation characteristics. The methods employed to accomplish the construction and installation activities are described in the following paragraphs. The baseline described is for the 3.5-year program. Variations necessary to accommodate the 4.5- and 6.5-year programs are noted. Schedules for all programs are shown in Figure 5-8. Factory-to-site transportation data are provided in Section 5.2; safety requirements are provided in Section 5.5.

# 5.3.1 Plant Construction

The sequential activities necessary for completing the total construction, installation, checkout and acceptance testing of any of the experimental plants are shown in Figure 5-9. Blocks 1 through 5 in the flow diagram identify the tasks covered in this section.

#### 5.3.1.1 Site Survey

The experimental plant site will be surveyed using standard techniques and equipment. The survey will establish:

- Field perimeter
- Power plant location
- Tower location
- Individual heliostat location

The most critical location is that of each heliostat, which will be established using the following procedures:

- Traverse track perimeter and set intermediate control points using a 1-sec theodolite and an electronic measuring device - set brass caps at boundary PIs and rebar with survey caps at intermediate points.
- Set straddles for intersection and intersect straddles for interior points.
- Run levels around perimeter and tie to USGS.
- Run interior level loops.
- Tie into state plane coordinate system.



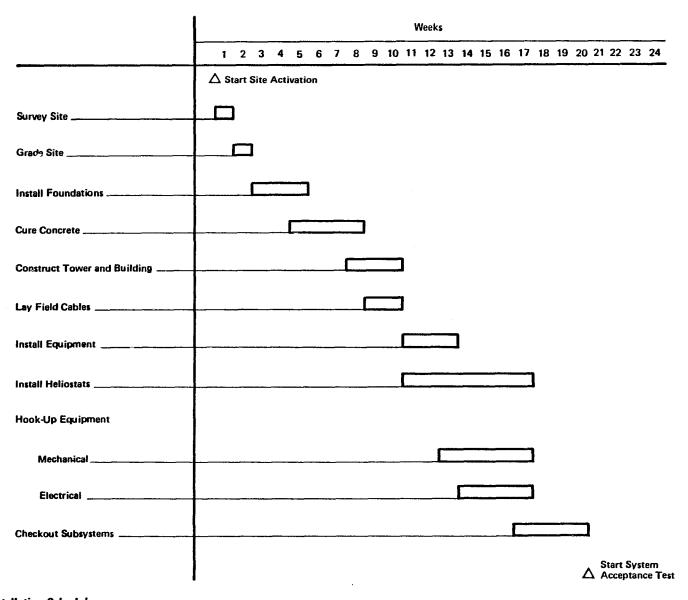


Figure 5-8. Installation Schedule

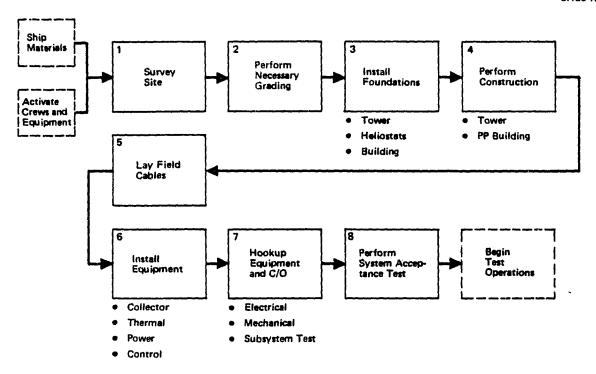


Figure 5-9. Experimental Plant Installation Flow

#### 5.3.1.2 Grading

Requirements for site grading will be site unique. It is expected that desert terrain will need only minimal ground contouring. Any grading that is found to be necessary will be accomplished using conventional equipment.

#### 5.3.1.3 Foundation Installation

The tower requires both a main foundation and a set of four guy anchors. The main foundation requires 36 cu yd of concrete for the slab and risers. The upper face of the slab will be 4 ft below grade, and the top of the risers will extend 6 in above grade. The upper faces of the guy anchors will be 5 ft below grade, and the four anchors will require 26 cu yd of concrete. In addition to the concrete, the foundation will also require 2700 lb of rebar.



Most of the EPGS equipment is light enough to be supported on a structural slab in the building and would not require separate foundations. The major exception to this is the turbine-generator which will require a separate formed foundation.

The baseline concentrator for the 3.5-year program, requires 217 heliostat foundations, each providing a bolted interface to the heliostat pedestal flange. These foundations will be installed using conventional construction equipment as follows:

- Excavate a hole for each heliostat at the exact location established by the survey crew.
- Install a prefabricated rebar cage, with welded-in pedestal attaching studs, in the foundation hole.
- Place temporary concrete forms around the rebar cage.
- Pour the predetermined quantity of premixed concrete into the foundation hole.
- Vibrate the poured concrete as necessary to fill possible voids.

The foundation design for the 4.5- and 6.5-year programs provides a different interface with the heliostat pedestal. Also a different quantity of foundations is required for each program - 171 for the 4.5 year, and 139 for the 6.5 year. This variation is described as follows:

The foundation will be a 0.61 m (2 ft) diameter drilled pier ombedded 6.71 m (22 ft) below grade. The drilled pier will have a 1.22 m (4 ft) extension above grade formed by a galvanized steel, tapered tube section filled with concrete. The pedestal will be force-mounted on this pier extension.

The procedure for emplacing the drilled pier foundations uses standard construction techniques. The cast in place concrete pier foundations can be used with most soil conditions. The pier hole will be excavated by drilling an open hole; if the sidewalls do not collapse, the reinforcement concrete will be placed as required to fill the hole. If the soil conditions are conducive to sidewall collapse, the pier can be placed by the Intrusion-Prepakt method, regardless of the sidewall stability. In this method, the hole is drilled and concrete grout displaces the soil as it is removed from



the hole in a single operation. Then, reinforcement will be forced into the grouted hole before the mortar begins to set. In any case, the pier will be installed with the 4-ft extension above grade.

The equipment required to emplace the heliostat foundations includes hydraulic cranes for lifting and manipulating ironwork and flatbed tractor/trailers for hauling the bracing materials. Hole drilling and concrete hauling equipment will be furnished by a contractor and included in the price of the service.

#### 5.3.1.4 Construction

The major construction at site is the assembly and erection of the collector subsystem tower, and the erection of the power plant building.

Tower construction will consist of the following:

- Fabrication of the tower should be done in the manner currently standard to the industry that is: shop detailing, fabrication, and delivery should be bid through local steel fabricators. Tower members will be cut to length, punched, painted, piece marked, preassembled, and delivered to the site with appropriate connection pieces and proper bolts.
- Delivery should be knocked down for ease of shipment. Two towers would easily fit on one tractor trailer.
- At the site tower sections are lifted into place sequentially with a mobile crane. Sections would each be about one quarter to one third of tower height.
- After tower is erected cables would be set and tensioned to a predetermined stress.
- Finish painting would most appropriately be done in the field as part of an overall painting contract. Prepainting of structural steel in the fabrication shop has not proven very effective: it requires special cleaning of the steel, special hard surface paint, special blocking in shipping to prevent marring, and joints which for structural reasons must be left bare, must be painted after erection.



Power plant building construction will consist of the following:

Normally the most efficient and least expensive method of purchasing a prefabricated metal building is to buy it erected. This is with erection by the supplier. This takes advantage of his skilled and specialized assembly crews special transports, and other special equipment.

It would probably be best if the supplier erected the building on foundations furnished by the general contractor. The latter will need other concrete on site and can therefore, get a better price for it.

#### 5.3.1.5 Lay Field Cables

The system design requires redundant power and control cables between the power plant building and the heliostats equipped with field controllers. Single cable runs are used between the heliostats with field controllers and those with simple controllers.

All cables will be layed in trenches and covered with back fill (direct burial). Trenches for the power and control cables will be prepared using a mini-cletrack equipped with a ditching attachment. This vehicle will also have a bulldozer blade attachment for use in back filling the trenches after the cables are in place.

Both power and control cables will be strung in the field by unreeling from pickup trucks. As the cables are placed in the ditches, care must be exercised to make sure that enough slack is provided to compensate for earth movement after the cables are buried. A loop of cable will be formed at each heliostat and left exposed from the ground. Later, these cable loops will be cut for connection into the heliostat circuit breaker box.

# 5.3.2 Equipment Installation

The tasks covered in this section are represented by Block 6 of the flow diagram in Figure 5-7. The baseline described is for the 3.5-year program. Variations necessary to accommodate the 4.5- and 6.5-year programs are noted. Schedules for all programs are shown in Figure 5-8.



#### 5.3.2.1 Collector

The collector subsystem includes the concentrator, the tower, and the receiver. Since construction of the tower has been described in Section 5.3.1, only the concentrator and the receiver installation is addressed here.

A. Concentrator--The concentrator is defined to include the heliostats, the controllers, the control and power distribution cabling, and the functional and hardware interfaces with the plant controller and power supply.

The control and power distribution cabling installation is covered in Section 5.3.1.5 and will not be repeated here.

The heliostats are received at site partially assembled and checked out. One unit which is delivered to the site is the pedestal/drive assembly. This assembly includes the pedestal, which bolts to the foundation, a circuit breaker box, the azimuth drive, elevation drives, the torque tube center section, either a heliostat field controller (HFC) or a heliostat controller (HC), limit switches, and an electrical cable assembly. These components are completely assembled at the factory, and all control, electrical, and mechanical functions are checked and verified to be operating properly.

The other unit delivered to the site is the reflector panel. This consists of six mirror modules assembled to the reflector structure. Two of these units are required per heliostat. Each is attached to the torque tube center section, after the pedestal/drive assembly has been installed on its foundation.

The tasks which must be performed to effect heliostate installation and checkout are shown in task flow form in Figure 5-10. On a single heliostat basis, these tasks are sequential; however, on a field basis, they are performed in parallel. The activities involved in each task are described in the following paragraphs, which are keyed to the block number.



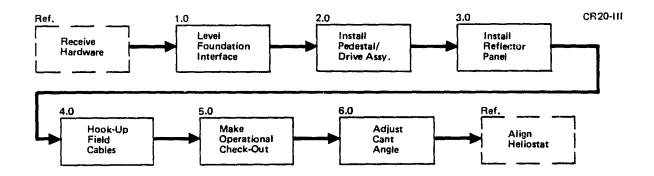


Figure 5-10. Heliostat Installation Task Flow

- 1. Task 1.0 Level Foundation Interface--To attain proper verticality of the heliostat it is necessary that a level interface exists between the foundation and the pedestal lower flange. This is accomplished by setting three of the foundation jacking nuts to a common level plan, and then locking them in place. Leveling is accomplished by the use of a bubble level tool specifically designed for this task.
- 2. Task 2.0 Install Pedestal/Drive Assembly--The pedestal/drive assembly arrives at site on a flatbed trailer. The trailer is positioned in the field close to the heliostat foundation. Each assembly is hoisted from the trailer, using a mobile crane, and installed on the foundation with the circuit breaker box in the due south position. Before lowering the pedestal assembly for the 3.5-year program onto the three leveled and locked jacking nuts, all other jacking nuts must be positioned below the plane of the three locked nuts. Once the pedestal flange is resting on the leveled nuts, anchor nuts are installed over the leveled nuts. Following this, the remaining jacking nuts are positioned against the lower face of the pedestal flange. Then the remaining anchor nuts are installed, and all anchor nuts are torqued to the specified value.

The major variations for the 4.5 and 6.5 Year programs, result from the difference in the heliostat foundation configuration, see Section 5.3.1.3. Because of this difference, Task 1.0, Level Foundation Interface, is eliminated from the 4.5-year and 6.5-year programs.



- 3. Task 3.0 Install Reflector Panels—The reflector panels arrive at site packaged four in a reusable container. The container is brought to site on a low-boy trailer, which is positioned adjacent to the pedestal/drive on the foundation. Using a mobile crane, the panels are removed from the container and positioned so that the panel attach interface mates with the torque tube flange. Attaching bolts are installed and torqued to the specified value.
- 4. Task 4.0 Hookup Field Cables -- When the field cables are layed, an exposed loop of cable is left at each heliostat foundation. To hook up the field cables to the heliostat, this loop must be cut and the ends of the cables inserted into the circuit breaker box on the pedestal. Then the wires are stripped and connected to the terminal blocks in the box.
- 5. Task 5.0 Make Operational Checkout--This task assures the proper operation of each installed heliostat. Field power and a portable control unit (PCU) are required, along with some standard electrical test equipment. After verifying proper current phasing and voltage at the circuit breaker box, the circuit breaker is closed and the PCU is hooked up with the heliostat. The heliostat is then commanded to operate through its normal modes and its responses are verified to be correct.
- 5. Task 6.0 Adjust Cant Angle--Within the heliostat field, five different cant angles are required to properly focus heliostats on the receiver. These angles vary with heliostat position as established by five bands in the field. The required adjustment is effected by installing the proper shim kit in heliostats within the five bands. There are five configurations of shim kits. The shims are installed between the mirror modules and the reflector structure. This completes heliostat installation except for track alignment. This task is described in Section 5.4.

B. Receiver--Structural steel for the receiver will arrive at site as precut, prepunched and marked pieces. These pieces will be assembled at the top of the tower in a sequence permitting installation of the housing panels.

The abosrber is completely assembled and flow-checked at the factory. Assembly at the factory includes installation and test of the trace heating elements, and installation of the absorber insulation. Following assembly and checkout, the absorber is divided into two parts for transportation to site. At the site, the absorber halves are welded together again, and the complete absorber is hoisted to a convenient height for installation of its support members. As soon as the receiver structure is configured to accept the absorber, the absorber is hoisted into place, and its support members are tied into the structure. The fluid lines are then welded to the tower riser and downcomer lines.

The two receiver doors are hoisted into position in the receiver and attached to the structure. Once in place, the doors are operationally checked and adjusted for proper sealing of the absorber aperture.

As soon as all checks and adjustments to the absorber and doors are complete, the housing is installed and secured to the structure. The receiver exterior will be painted at the same time as the tower is painted.

#### 5.3.2.2 Energy Transport and Storage

The installation of energy transport and storage equipment requires that equipment of each system be available at site at the same time. Therefore, both systems are covered in this section.

The energy transport subsystem consists of a receiver loop, a steam generation loop, and an intertank transfer subsystem. The thermal storage subsystem consists of storage vessels, thermal storage medis, gaseous nitrogen supply, and immersion heaters.

The principal interfaces will include Hitec inlet and outlet lines from each storage tank, the Hitec inlet and outlet of the solar receiver, and the Hitec inlet and outlet of the steam generator.

Installation of these equipments starts with the unloading and emplacement of the two storage tanks and the steam generator. These heavy items are hoisted from the delivery trucks using the Linkbelt 65-ton crane. Each unit is installed on its foundation and secured in place. Then, the interconnecting plumbing is installed. The pipe runs are leak-checked, and valve operation is checked. When these integrity and operational checks are satisfactorily completed, the trace heating elements are installed and, along with the factory-installed immersion heaters, powered-up and checked for proper operation and power draw. The final operation involves installation of plumbing and tanks insulation, and the installation and checkout of the  ${\rm GN}_2$  system.

The energy transport subsystem for the 6.5-year configuration consists of a receiver loop and a steam generation loop. The thermal storage subsystem consists of a single tank, dual media thermocline storage design utilizing taconite and heat transfer salt (HTS), a gaseous nitrogen supply, and an immersion heater.

The major variation in this 6.5-year configuration from the baseline is that only one storage tank needs to be installed. Installation procedures are the same as described above for the two-tank system.

#### 5.3.2.3 Power Conversion

The function of the power conversion subsystem (PCS) is to convert the thermal energy stored in the Hitec/HTS into electricity. This electrical power is then supplied to the electrical transmission network and is also used to supply power to parasitic plant loops.



Installation of the PCS equipment is relatively simple and fast. The major items of equipment include the following:

- Turbine-generator and ancillary equipment
- Steam generator
- Feedwater heaters and piping
- Pumps
- Condenser and air removal equipment
- Heat rejection equipment
- Water treatment
- Auxiliary power unit
- Instrumentation and control valves
- Switchgear and plant electrical network

Since most of these items can be factory-installed on skids, site installation consists only of unloading the trucks and directly emplacing the skid-mounted components on their respective foundations. Unloading of the transport vehicles takes place in the lay-down area of the power plant building, using the overhead bridge crane. Once the equipment is installed, interconnecting plumbing and wiring is installed and checked out. Necessary insulation is installed on the plumbing runs.

The 6.5-year variations from the baseline consists of installing a radial turbine instead of an axial turbine, and an additional four feedwater heaters.

Once the radial turbine is implaced on its foundation at the plant site, the following connections will have to be made:

- A. Steam inlet line
- B. Feedwater extraction lines
- C. Condenser steam lines
- D. Condenser cooling water (delivery and return)
- E. Lube supply cooling water (delivery and return)
- F. Chemical feed unit supply lines
- G. Auxiliary lube supply pump motor electric power
- H. Instrumentation and alarm electric power
- Generator electrical hookup (see below)



Handling requirements of the skid mounted turbine/gearbox/generator assembly are dictated by these specifications:

- A. Gross weight of approximately 7.5 tons
- B. Overall dimensions of 5 ft wide x 11 ft long x 6 ft high

#### 5.3.2.4 Plant Control

The plant control system is an overall command, control, and data acquisition system that performs control, control management, supervision, data collection and display functions for each subsystem. The purpose of the plant control subsystem is to provide control of subsystem elements (e.g., motors, valves, mirrors, etc) and integrate the independent controls of each subsystem (i.e., collector, receiver, storage, power generation) to achieve single point (console) control and evaluation of the plant processes.

The electronic and display components of the PCS are assembled into complete operating units at the factory. These units are all functionally checked out at the factory prior to shipment to the site. The site installation activities needed are to:

- A. Unload the transport vehicle in the power plant building area
- B. Hoist the units to the mezzanine floor of the power plant building
- C. Position each unit at its assigned position in the control room
- D. Perform electrical and communication interface hookup

#### 5.4 CHECKOUT AND ADJUSTMENT

## 5.4.1 Heliostat Alignment

Precise orientation of each heliostat will be required in order to optimize the accuracy of reflected beams on the receiver. Analyses have shown that errors of reference angles, tilt of azimuth axis from vertical, orthagonality of elevation plane and azimuth plane, position of azimuth and elevation pivot points, latitude, longitude and time can degrade beam accuracy.



After installation of the heliostat on its foundation, the cant angles of each mirror module will be adjusted to allow for fault correction and fine tuning. Each heliostat will be aligned using the Sun, an active target, and a computer. Gimbal angles will be calculated for the most accurate reflection of the beam on the target. With an active target, the difference between the commanded image centroid and the achieved image centroid can be determined by visual observation.

With two independent measurements taken during the day, gimbal axis encoder readings will be used to construct four equations with four unknowns (two reference angles and two tilt angles). Correction angles obtained will be used in the heliostat controller software to control heliostat tracking on the target.

The detailed alignment procedure for open-loop control of a heliostat is as follows:

- A. Latitude and longitude of foundation bench mark are surveyed. The south reference is surveyed. Angle accuracy is ± 5°.
- B. The heliostat is installed so that the center of the azimuth pivot point is known to within  $1-ft^2$  volume. The pedestal is then installed on the foundation so that the centerline is within  $\pm$  2° of the local vertical. These tolerances are considered to be normal for field construction.
- C. A mobile test unit is connected to the heliostat controller. As an alternate, the heliostat can be operated in the control room.
- D. The heliostat is driven until mirror normal is at a standby tracking point (Figure 5-11).
- E. The heliostat array controller or computer is notified that heliostat X is ready for initial alignment, and the surveyed location information of this heliostat is stored in the computer memory.
- F. Gimbal angles are calculated to control movement resulting in the reflected beam hitting the alignment target. If the beam is not on target, an observer will identify necessary corrections. Gimbal axis readings and Sun position are then recorded.



- G. While the reflected beam is on the target, the computer commands a l- to 2-minute open-loop track. The reflected beam location on target is recorded.
- H. The heliostat is placed into an alignment standby mode where the reflected beam points at a space near the target.
- I. One to two hours later, the heliostat is commanded to point the reflected beam onto the target. After a 5- to 30-second period of open-loop tracking, the location of the beam is recorded.
- J. The heliostat is commanded to the stowage position. Alignment data for this heliostat are now in the computer permanent memory.

This procedure is illustrated in Figure 5-11.

# 5.4.2 Plant Control System Checkout and Adjustment

Prior to commissioning the small power system plant for service, initial field checkout, adjustment, and tuning of plant controls will be performed. Each control point will be verified as operational prior to startup. Each subsystem will be tested to the operational extent possible. A final all-up control system integration test will be conducted in each of the plant operating modes to verify special supervisory control algorithms and fine-tuning adjustments of each control point.

# 5.4.3 Radial Turbine Checkout - 6.5-Year Program

After initial installation of the radial turbine, the following checkout will be performed:

- A. Check sump for proper amount of lube oil
- B. Verify clean oil filter is installed
- C. Verify that calibration dates of the following components are current:
  - 1. Shaft axial position probes
  - 2. Vibration probes



Figure 5-11. Heliostat Alignment

- 3. Lube oil pressure and temperature gauges
- 4. High oil temperature and low oil pressure switches
- D. Check pressure and flow rate of water supply for oil cooling
- E. Check that turbine seal drain is properly vented (not plugged)

Additional checks will be made when the turbine is initially activated as part of the power conversion subsystem. Adjustments are unnecessary during checkout of the turbine.

## 5.5 SAFETY ASPECTS (INSTALLATION)

The specific safety requirement during installation (construction) will be controlled by the federal OSHA regulations (Title 29, Chapter XVII, Part 1926), applicable state and local regulations and solar specific internal safety procedures. The internal safety procedures will include salt handling procedures for the Hitec heat transfer fluid to prevent skin and eye damage and possible toxic problems from human injestion.

The major solar plant specific safety problem involves the reflected concentrated solar energy from the heliostats. This subject is discussed in detail in Section 4.1.3 and may involve specific safety procedures and features during installation and testing of the several heliostats. Heliostat panel covers or dark glasses may be necessary during installation to prevent unsafe eye exposure to other construction workers. Specific operational procedures, and possible personnel exclusion areas, will be required for heliostat checkout.



# Section 6 MAINTENANCE AND REPAIR CHARACTERISTICS

Plant maintenance, as determined to date, is identified in the following subsection. The level of detail and confidence in the requirement estimates at this time are constrained by the current hardware design definition. The basic corrective and scheduled maintenance tasks for the collector subsystem have been determined by a hardware analysis to identify maintenance actions. These maintenance actions result from equipment failures or may be scheduled actions such as cleaning or lubrication to prevent equipment deterioration or to sustain performance characteristics.

Because of the high predicted reliability of plant hardware and the maintain-ability characteristics, the product of maintenance actions and mean time to repair was approximately 2300 manhours per year. This low annual demand for maintenance labor, in combination with the many diverse skills required, supports the following two maintenance concepts, one for a single plant and one for multiple plants.

- A. Maintenance Concept Experimental Plant
  - Scheduled Maintenance
     Light tasks to be handled by the plant operator.
     Heavy tasks to be combined and performed during a planned outage.
  - Corrective Maintenance
     To be performed by skilled factory technicians on a call basis.
     Computer maintenance to be done under a support contract by the manufacturer.
  - 3. Repair
    Discrepant components to be repaired at the manufacturer's facility.
  - Provide minimum quantities of long-lead-time spares.
- B. Maintenance Concept Commercial Plants Establish a central maintenance facility which will:
  - 1. Support multiple plants
  - 2. Provide at-site maintenance



- 3. Provide off-site repair
- 4. Establish and maintain a common spares depot
- 5. Monitor plant equipment operation

Implementation of either of these proposed concepts will eliminate the need for costly maintenance crews in residence at the plant. Implementation of the commercial maintenance concept will drastically reduce capital investment in maintenance equipment and spares, calculated on a site basis.

For clarity, the terms scheduled maintenance and corrective maintenance are defined as follows:

A. Scheduled Maintenance — Actions performed to retain an item in an operable condition by systematic inspection, detection, prevention of incipient failures, replacement of life/cycle limited components, adjustment, calibration, cleaning, and lubrication. Scheduled preventive actions will be minimized during operating periods and emphasized during nonoperating periods of portions of the thermal storage subsystem to sustain equipment/system availability. Servicing activities will be minimized and conducted on a noninterference basis.

In addition to these scheduled procedures, plant operation will be continuously monitored for out-of-specification performance. When component and subsystem deviates from established norms, operations will notify maintenance and corrective procedures will be established that will provide rapid return to establish performance levels with a minimum of outage time.

B. Corrective Maintenance — Actions performed to restore an item to a satisfactory condition by correction of known or suspected malfunctions or defects that have caused degradation of the item below the specified performance level.

Corrective maintenance consists of repair, replacement, checkout, and verification of repaired equipment. It is performed as a result of condition monitoring, or unexpected or unpredicted failure or malfunction.



#### 6.1 RELIABILITY/AVAILABILITY

The results of the reliability/availability analysis for the 3.5-year, 4.5-year, and 6.5-year programs are presented along with the details of the methodology and data sources in Volume V, Section 2.2.

The results of the study indicate that overall availability for this type of system should be 0.95, with small variations due to design specifics. The 3.5-year program with an axial turbine, a dual tank energy storage subsystem, and 217 heliostats has a projected availability of 95.09%. The 4.5-year system with the same power generation and energy storage, but with only 171 heliostats, has a projected availability of 95.15%. The 6.5-year program with a radial turbine, a single tank energy storage subsystem, and 139 heliostats has an availability of 94.96%.

The loss of a single heliostat, or a few heliostats, will not directly affect the system availability because a system outage of less than 2% is not counted as a forced outage. Losses greater than 2% are counted as either partial forced outages or total forced outages depending on the magnitude of the outage. In this study, the concept of partial forced outages was not used due to a very small probability of losing several heliostats at the same time, and the fact that the remainder of the system is a single-thread design, which means that any critical failure will cause a total shutdown. The probability of losing one heliostat in one operating day is 0.15 for the 3.5-year system (and even less for the 4.5- and 6.5-year programs) and 0.0225 for losing two heliostats in one day. Loss of four heliostats (probability of 0.00051) would result in less than a 2% loss of power.

However, some failures on a single heliostat (failure of power or control cables) will cause a loss of 32 heliostats because power must be removed from all heliostats on that circuit in order to effect the repair. In addition, failure of a heliostat field controller will cause the loss of 32 heliostats. These failures are classed as critical and appear in critical failure classifications in Volume V, Section 2.2.



The large difference between the total failures per year value for the collector subsystem and the critical failures per year, failures which will cause a system shutdown, show that most failures in the heliostat field will not cause a system shutdown.

The reduction in collector system total failures, critical failure, and forced outage hours from the 3.5-year program, to the 4.5-year program, to the 6.5-year program reflects the reduction in the number of heliostats from 217 to 171 to 139. The corrective maintenance values also reflect this reduction. Most of the preventative maintenance values shown for the collector subsystem are reflected in heliostat mirror washing operations. The details of the maintenance analysis are discussed in Section 6.2.

The cumulative mean-time-to-failure (CMTBF) and the cumulative mean-time-to-recover (CMTTR) are calculated by dividing the operating time per year by the number of critical failures per year, and the forced outage hours per year by the number of critical failures per year.

The difference in failure characteristics in the energy storage subsystems for the 3.5- and 4.5-year programs reflects the change from a two-tank system to a single-tank dual-media system with the reduction of system components (see Volume V, Section 2.2). The increase in failure characteristics of the power conversion subsystem of the 6.5-year program over the 3.5- and 4.5-year programs reflects the change to the radial turbine with four closed feedwater heaters, as opposed to the axial turbine with no closed feedwater heaters.

The radial turbine offers many reliability and maintenance advantages over the axial turbine.

- A. Disassembly is easy because all rotary blade rows are mounted on a single disc.
- B. Turbine rotor balancing is simplified because of the single disc.
- C. Only one shaft seal is required between turbine and gearbox.
- D. Bearing thrust load is greatly reduced.

- E. Bearing seals have a service life of 20,000 hours; replacement is accomplished without opening turbine and gearset housings. Upper half of seal can be removed without disturbing steam lines or lubrication plumbing.
- F. Double-helical gears allow symmetrical bearing loads for more uniform tooth contact.
- G. Through-hardened gears are less sensitive to shock loads than surface-hardened gears; and adjust to slight misalignment caused by thermal or load deflections.

The preventive maintenance (planned outage) downtime is shown for each subsystem. Specifically this represents the downtime required to clean heat exchanger (steam generator and feedwater heaters) tubes and perform seasonal maintenance on the turbine and generator. However, it is assumed that all of this maintenance would be scheduled at the same time; therefore, only the longest downtime (104 hours for the turbine) is charged as overall system downtime.

The results of this analysis can be compared to the historial experience of conventional power generating plants as reported in Reference 6-1.\* The data show that operating availability and outages (forced and planned) are strong functions of plant size. Availability decreases and outages increase with greater plant size. There is little information on power plants in the 1-MW range, but extrapolations of the data from larger power plants indicate that the forced outage from a 1-MW plant should be about 2.5%. This compares with the results of this study which range from 1.88 to 2.07%. The lower value from the study probably reflects the relatively simplified designs available at this state of the program. It would be expected that as the design matures, the design will contain more components. Historical data indicate that the planned outage should be about 5.5%, as opposed to the study results of 2.97%. This is due to the fact that the solar system operates only 40% of the time; therefore, preventative maintenance can be performed on a 24-hour basis, but is only charged at a 0.6 hour basis. The charged planned outage may be somewhat high, based on this comparative analysis, indicating that the critical planned outage may be less.

<sup>\*</sup>Listed at the end of the section.



The extrapolated availability value is 94% as compared with analysis results of 94.96 to 95.15%. This higher availability is the result of the advantage of the charged-versus-actual planned outage time.

The historical data indicate a maintenance manhours (MMH) level of 2500 hrs as opposed to a calculated 2038 to 2390 hrs. Again, this is probably due to the level of maturity of system design.

#### 6.2 INSPECTION AND MAINTENANCE

Maintenance analyses were conducted on all components of the experimental system design. The following sections present the results of these analyses.

# 6.2.1 Ground Rules and Assumptions

Due to the one-time nature of this program, the maintenance concepts were intended to yield maximum system availability consistent with low costs. A summary of basic O&M philosophy follows.

- A. For field maintenance, removal and replacement of failed line replaceable units (LRUs) is proposed. However, most forms of purely structural repair is accomplished in-place.
- B. Initial spares were determined on the basis of a 30-day contingency, along with quantities required to fill supply pipelines. Location of suppliers of spare parts was considered in determining order lead times.
- C. A 1-month turnaround was assumed for off-site repair; a 1-week turnaround for on-site repair.

Maintenance activities are categorized as follows:

- On-equipment corrective maintenance
- Off-equipment on-site repair
- Off-equipment off-site repair
- On-equipment scheduled maintenance

Summaries of manpower and spares requirements by the above maintenance categories, for each component, appear as Tables 6-1 through 6-9. Maintenance equipment is identified in Table 6-10.



ITEM	F/R 10 <sup>-6</sup>	MTTR	CREW SIZE	POPULA- TION	ANNUAL MANHOURS	INITIAL SPARES	ANNUAL REP. SPARES	DISCARD FACTOR
COLLECTOR SUBSYSTEM:								
Power Cables	.108	1.5	2	217 sets	0.27	2 sets	.090 sets	1.0
Control Cables	.108	1.5	· 2	217 sets	0.27	2 sets	.090 sets	1.0
Heliostat Controller	26.22	2.2	2	210	93.54	4	1.063	.05
Field Controller	43.25	2.2	2	7	5.14	2	0.058	.05
Motor, Elev. and Az.	2.0	1.9	2	434	12.74	2	0.168	.05
Harmonic Drive	1.65	4.0	4	217	22.12	2	0.069	.05
Linear Actuator	2.94	2.2	2	217	10.84	2	0.123	.05
Optical Encoder, Az.	1.35	2.7	2	434	12.22	2	0.113	.05
Optical Encoder, Elev.	1.35	1.1	2	651	7.47	2	0.170	.05
Pedestal	0.1	1.0	2	217	0.38	0	0	0
Structure	0.5	1.5	2	217	2.85	0	0	0
Mirror Module -	6.0/Hel.	2.0	2	217 Hel.	45.62	2	11.406	1.0
Storage Motor	2.0	1.9	2	217	0.27	2	0.004	.05
Storage Linear Actuator	2.94	2.2	2	217	0.46	2	0.005	.05
Field Control Cables	.108	2.5	2	217 sets	0.45	2 sets	0.090 sets	1.0
Field Power Cables	.108	2.5	2	217 sets	0.45	2 sets	0.090 sets	1.0
Az. Limit Switch	1.87	2.0	2	434	12.53	2	3.134	1.0
Elev. & Stor. Limit Swit	ch 1.87	1.1	2	868	13.79	2	6.267	1.0
Circuit Breaker & Switch	1.0	1.6	2	217	2.68	2	0.838	1.0
HAC/Field Control Cables	.108	2.5	2	7 sets	015	l set	.003 sets	1.0
HAC/Field Power Cables	.108	2.5	2	7 sets	.015	1 set	.003 sets	1.0
Absorber	1.6	14	4	1	7.850	0	0	٥
Absorber Support Struc.	1.0	10	4	1	.350	0	0	0
Absorber Door	1.0	8	4	1	.280	0	0	0
Absorber Piping	1.0	12	4	1	.420	٥	0	0
Vent Valve	*5.23/d,1.72/ hr	5.2	2	1	.109	1	.001	.05

<sup>\* 1</sup> demand/week

Table 6-1. On-Equipment Corrective Maintenance, 3.5-Year System

Page 2 of 3

ITEM	F/R 10 <sup>-6</sup>	MITR	CREW SIZE	POPULA- TION	ANNUAL MANHOURS	INITIAL SPARES	ANNUAL REP. SPARES	DISCARD FACTOR
COLLECTOR SUBSYSTEM: (Con	ł l						-	
Relief Valve	10	4.5	2	1	.347	2	.002	.05
Trace Heating	10	20	. 2	1	1.544	0	0	O
Insulation	1.0	10	2	1	.077	0	0	0
Hand Valves	0.1	4.5	2	2	.006	1	0	.05
Sensors	1.0	4.0	2	20	.618	1 set	.077	1.0
Motor (Door)	2.0	3.0	2	1	.001	1	o	.05
ENERGY STORAGE SUBSYSTEM:								į
Hand Valves	0.3	4.5	2	5	.052	1	0	.05
Check Valves	4.0	4.5	2	2	.278	1	.002	.05
Regulator	18.0	5.7	2	2	1.585	1	.007	.05
Sensor	1.0	3.0	2	20	.463	1	.077	1.0
Relief Valves	10.0	4.5	2	2	.695	1	<b>"</b> 004	.05
Heaters	0.4	10.0	2	20	.016	1	0	o
Tanks	1.0	10.0	2	2	.350	1	0	0
ENERGY TRANSPORT SUBSYSTEM:							-	
Control Valves	6.46	5.7	2	3	.853	2	.004	.05
Remote Valves	*5.23/d, 1.72/ hr.	5.2	2	6	.653	2	.003	.05
Check Valves	4.0	4.5	2	1	.139	1	.001	.05
Hand Valves	0.3	4.5	2	19	.198	1	.001	.05
Pumps	1000/d, 30/hr	9.7	2	2	18.120	2	.047	.05
Sensors	1.0	3.0	2	5	.116	1	.019	1
Heat Exchangers	1.8	10.0	2	3	.378	1	0	.02
Heaters	10.0	20.0	2	1	3.504	2	.002	.02
* 2 domanda/day								

Table 6-1. On-Equipment Corrective Maintenance, 3.5-Year System

Page 3 of 3

ITEM	F/R 10 <sup>-6</sup>	MTTR	CREW SIZE	POPULA- TION	ANNUAL MANHOURS	INITIAL SPARES	ANNUAL REP. SPARES	DISCARD FACTOR
POWER CONVERSION SUBSYSTEM	1							
Axial Turbine	102.0	40.0	3	1	42.889	0	0	0
Generator	80.0	40.0	3	1	33.638	0	0	o
Condensor	1.0	10.0	3	1	0.105	0	0	O
Tank	1.0	10.0	3	8	0.841	0	0	0
Deaerator	1.0	10.0	3	1	0.105	0	0	o
Pump	1000/d, 30/hr.	* 9.7	2	5	44.329	2	.114	.05
Control Valve	6.46	4.7	2	11	2.340	2	.012	.05
Hand Valve Type 1	0.3	3.5	2	108	0.795	2	.006	.05
Hand Valve Type 2	0.1	3.5	2	29	0.071	1	.001	.05
Pressure Sensor	1.0	2.0	2	20	0.280	2	.070	1.0
Flow Sensor	12.0	3.5	2	2	0.589	2	.084	1.0
Level Sensor ~	1.0	2.0	2	16	0.224	2	.056	1.0
Relief Valve	. 10.0	3.5	2	9	2.207	2	.016	.05
Remote Valve	5.23/d, 1.72/h	4.2	2	26	2.151	2	.013	.05
Flow Meter	12.0	3.5	2	2	0.589	2	.084	1.0
Level Meter	1.0	2.0	2	2	0.028	1	.007	1.0
Heat Exchanger	1.8	10.0	2	2	0.252	0	0	0
Check Valve	4.0	4.5	2	4	0.505	2	.003	.05
Cooling Tower Structure	1.0	10.0	2	1	0.175	0	0	0
Cooling Tower Tanks	1.0	10.0	3	3	0.788	0	0	O
								-
* 1 demand/day ** 2 demands/day								

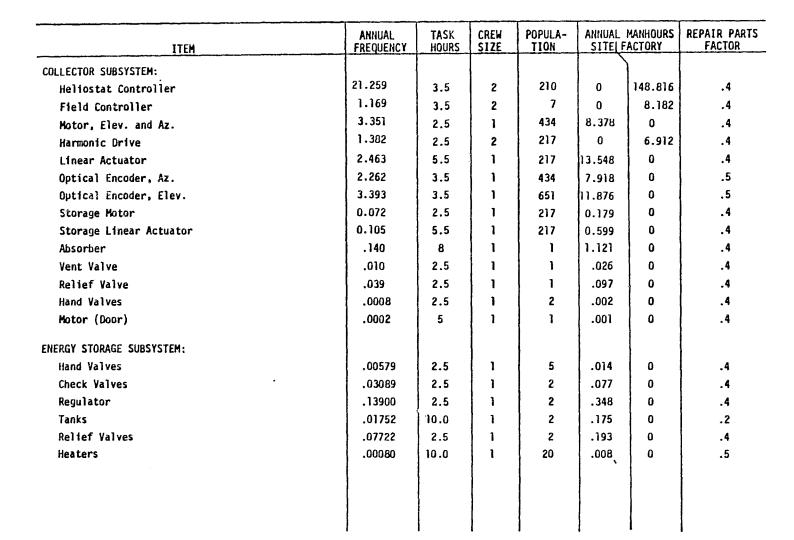


Table 6-2. Off-Equipment Repair, 3.5-year System

Page 2 of 2

ITEM	ANNUAL FREQUENCY	TASK HOURS	CREW SIZE	POPULA- TION	ANNUAL MANHOURS SITEL FACTORY		REPAIR PARTS FACTOR	
ENERGY TRANSPORT SUBSYSTEM:								
Control Valves	.07483	2.5	1	3	.187	0	.4	
Remote Valves	.06276	2.5	1	6	.157	0	.4	
Check Valves	.01544	2.5	1	1	.039	0	.4	
Hand Valves	.02201	2.5	1	19	.055	0	.4	
Pumps	.93400	16.0	] 1	2	14.944	0	.4	
Heat Exchangers	.01892	16.0	1	3	.303	0	.2	
Heaters	.08761	10.0	1	1	.876	0	.2	
POWER CONVERSION SUBSYSTEM:							ŀ	
Pamp	2.28500	6	1	5	3.710	0	.4	
Control Valve	.2490	2.5	1	11	.622	0	.4	
Hand Valve Type 1	.1135	2.5	1	108	.284	0	.4	
Relief Valve	.31536	2.5	1	9	.788	0	.4	
Remote Valve	.2561	2.5	1	26	-640	e	.4	
Check Valve	.05606	2.5	1	4	.140	0	.4	
Hand Valve Type 2	.01016	2.5	1	29	.025	0	.4	
•					,			
			1			1		

Table 6-3. On-Equipment Scheduled Maintenance, 3.5-Year System

ITEM	ANNUAL FREQUENCY	TASK HOURS	CREW SIZE	POPULA- TION	ANNUAL MANHOURS	ANNUAL CONSUMABLES
COLLECTOR SUBSYSTEM: .						
Heliostat Field Corrosion/Structural Inspection	1	4	2	1	8	o
Mirror Modules' Cleaning	12	.133/Hel	2	217 Hel.	692.6	130 gal. clear ing agent 16,926 gal. deionized wate
Receiver Tower Leak/Corrosion Inspection	12	1	1	1	12	0
HERGY STORAGE SUBSYSTEM:						
Visual Inspection for Leaks/Corrosion (Includes Energy Transport Subsystem Components)	1	1	1	1	1	o
HERGY TRANSPORT SUBSYSTEM:						İ
Heat Exchanger Cleaning	1/3 years	48	2	3	96	0
OHER CONVERSION SUBSYSTEM:						
Turbine/Generator Oil Check	49	2	1	1	98	0
Turbine/Generator Trip Test, Gen. Winding Inspect.	4	4	1	1	16	0
Turbine/Generator Stop Valve, Gear Teeth Check	2	2	1	1	4	0
Turbine/Generator Oil System, Valves, Bearings Check	1	8	1	1	8	O
Turbine/Generator Vibration Test, Overhaul	· 1	180	3	1	540	0
Chem. Feed Tanks' Replenishment	25	1	2	4	200	0
Heat Exchanger Cleaning	1/3 years	48	2	2	64	0
Condensor Cleaning	1/3 years	48	2	1	32	0
Deaerator Cleaning	1/3 years	48	2	1	32	0

Table 6-4. On-Equipment Corrective Maintenance, 4.5-Year System

ITEM	F/R 10 <sup>-6</sup>	MTTR	CREW SIZE	POPULA- TION	ANNUAL Manhours	INITIAL SPARES	ANNUAL REP. SPARES	DISCARD FACTOR
COLLECTOR SUBSYSTEM:								
Power Cables	.108	1.5	2	171 sets	.21	2 sets	.071 sets	1.0
Control Cables	.108	1.5	· 2	171 sets	.21	2 sets	.071 sets	1.0
Heliostat Controller	5.79	2.2	2	165	16.23	2	. 184	.05
Field Controller	9.74	2.2	2	6	.99	2	.011	.05
Motor, Elev. and Az.	2.0	1.9	2	342	10.94	2	.132	.05
Harmonic Drive	1.65	4.0	4	171	17.43	2	.054	.05
Linear Actuator	2.94	2.2	2	171	8.54	2	.097	.05
Optical Encoder, Az.	1.35	2.7	2	342	9.63	2	.089	.05
Optical Encoder, Elev.	1.35	1.1	2	513	5.88	2	.134	.05
Pedestal	0.1	1.0	2	171	.30	0	0	0
Structure	0.5	1.5	2	171	2.25	0	0	0
Mirror Module -	6.0/Hel.	2.0	2	171 Hel.	35.95	2	8.988	1.0
Storage Motor	2.0	1.9	2	171	.21	2	.003	.05
Storage Linear Actuator	2.94	2.2	2	171	36	2	.004	.05
Field Control Cables	.108	2.5	2	171 sets	.36	2 sets	.071 sets	1.0
Field Power Cables	.108	2.5	2	171 sets	.36	2 sets	.071 sets	1.0
Az. Limit Switch	1.87	2.0	2	1	9.88	2	2.469	1.0
Elev. & Stor. Limit Swit	h 1.87	1.1	2	684	10.86	2	4.939	1.0
Circuit Breaker & Switch	1.0	1.6	2	171	2.11	2	.660	1.0
HAC/Field Control Cables	.108	2.5	2	6 sets	.01	1 set	.003 sets	1.0
HAC/Field Power Cables	.108	2.5	2	6 sets	.01	1 set	.003 sets	1.0
Absorber	1.6	14	4	1	7.850	0	0	O
Absorber Support Struc.	1.0	10	4	1	.350	0	0	0
Absorber Door	1.0	8	4	1	.280	0	0	0
Absorber Piping	1.0	12	4	1	.420	0	0	0
Vent Valve	*5.23/d,1.72/ hr	5.2	2	1	.109	1	.001	.05

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Table 6-4. On-Equipment Corrective Maintenance, 4.5-Year System

ITEM	F/R 10 <sup>-6</sup>	MTTR	CREW SIZE	POPULA- TION	ANNUAL MANHOURS	INITIAL SPARES	ANNUAL REP. SPARES	DISCARI Factor
COLLECTOR SUBSYSTEM: (Co	1 1							
Relief Valve	10	4.5	2	1	.347	2	.002	.05
Trace Heating	10	20	· 2	1	1.544	0	0	0
Insulation	1.0	10	2	1	.077	0	0	0
Hand Valves	0.1	4.5	2	2	.006	1	0	.05
Sensors	1.0	4.0	2	20	.618	1 set	.077	1.0
Motor (Door)	2.0	3.0	2	1	.001	1	0	.05
ENERGY STORAGE SUBSYSTEM	.		1					
Hand Valves	0.3	4.5	2	5	.052	1	0	.05
Check Valves	4.0	4.5	2	2	.278	1	.002	.05
Regulator	18.0	5.7	2	2	1.585	1	.007	.05
Sensor	1.0	3.0	2	20 .	.463	1	.077	1,6
Relief Valves ~	10.0	4.5	2	2	.695	1	.004	.05
Heaters	0.4	10.0	2	20	.016	1	0	0
Tanks	1.0	10.0	2	2	.350	1	0	0
ENERGY TRANSPORT SUBSYSTEM:							-	 
Control Valves	6.46	5.7	2	3	.853	2	.004	.05
Remote Valves	*5.23/d, 1.72/ hr,	5.2	2	6	.653	2	.003	.05
Check Valves	4.0	4.5	2	1	.139	1	.001	.05
Hand Valves	0.3	4.5	2	19	.198	1	.001	.05
Pumps .	1000/d, 30/hr	9.7	2	2	18.120	2	.047	.05
Sensor <b>s</b>	1.0	3.0	2	5	.116	1	.019	1
Heat Exchangers	1.8	10.0	2	3	.378	1	0	.02
Heaters	10.0	20.0	2	1	3.504	2	.002	.02

. ITEM	F/R 10 <sup>-6</sup>	MTTR	CREW SIZE	POPULA- TION	ANNUAL MANHOURS	INITIAL SPARES	ANNUAL REP. SPARES	DISCARD FACTOR
POWER CONVERSION SUBSYSTEE	1							
Axial Turbine	102.0	40.0	3	, ,	42.889	0	0	0
Generator	80.0	40.0	. 3	1	33.638	0	0	0
Condensor	1.0	10.0	3	1	0.105	0	0	0
Tank	1.0	10.0	3	8	0.841	0	0	0
Deaerator	1.0	10.0	3	1	0.105	0	0	O
Pump	1000/d. 30/hr.	* 9.7	2	5	44.329	2	.114	.05
Control Valve	6.46	4.7	2	11	2.340	2	.012	.05
Hand Valve Type 1	0.3	3.5	2	108	0.795	2	.006	.05
Hand Valve Type 2	0.1	3.5	2	29	0.071	1	.001	.05
Pressure Sensor	1.0	2.0	2	20	0.280	2	.070	1.0
Flow Sensor	12.0	3.5	2	2 .	0.589	2	.084	1.0
Level Sensor -	1.0	2.0	2	16	0.224	2	.056	1.0
Relief Valve	. 10.0	3.5	2	9	2.207	2	.016	.05
Remote Valve	5.23/d <b>,</b> 1.72/hi	4.2	2	26	2.151	2	.013	.05
Flow Meter	12.0	3.5	2	2	0.589	2	.084	1.0
Level Meter	1.0	2.0	2	2	0.028	1	.007	1.0
Heat Exchanger	1.8	10.0	2	2	0.252	0	0	0
Check Valve	4.0	4.5	2	4	0.505	2	.003	.05
Cooling Tower Structure	1.0	10.0	2	1	0.175	0	0	0
Cooling Tower Tanks	1.0	10.0	3	3	0.788	0	0	0
·								
* 1 demand/day ** 2 demands/day				•				

ITEM	ANNUAL FREQUENCY	TASK HOURS	CREW SIZE	POPULA- TION		MANHOURS ACTORY	REPAIR PARTS FACTOR
COLLECTOR SUBSYSTEM:	,					)	
Heliostat Controller	3.689	3.5	2	165	0	25.820	.4
Field Controller	.226	3.5	2	6	0	1.579	.4
Motor, Elev. and Az.	2.641	2.5	1	342	6.602	0	.4
Harmonic Drive	1.089	2.5	2	171	0	5.447	.4
Linear Actuator	1.941	5.5	1	171	0.676	0	.4
Optical Encoder, Az.	1.783	3.5	1	342	6.239	0	.5
Optical Encoder, Elev.	2.674	3.5	1	513	9.359	0	.5
Storage Motor	.056	2.5	1	171	.141	0	.4
Storage Linear Actuator	.083	5.5	1	171	.456	0	.4
Absorber	.140	.8	1	1	1.121	0	.4
Vent Valve	.010	2.5	1	1	.026	0	.4
Relief Valve	.039	2.5	1	] ]	.097	0	.4
Hand Valves	.0008	2.5	1	2	.002	0	.4
Motor (Door)	.0002	5	1	1	.001	0	.4
ENERGY STORAGE SUBSYSTEM:			1				
Hand Valves	.00579	2.5	1	5	.014	0	.4
Check Valves	.03089	2.5	1	2	.077	0	.4
Regulator	.13900	2.5	1	2	.348	0	.4
Tanks	.01752	10.0	1	2	.175	0	.2
Relief Valves	.07722	2.5	1	2	.193	0	.4
Heaters	.00080	10.0	1	20	.008	0	.5
•							

Table 6-5. Off-Equipment Repair, 4.5-Year System

Page 2 of 2

FREQUENCY	TASK HOURS	CREW SIZE	POPULA- TION	SITELFA	ANHOURS CTORY	REPAIR PARTS FACTOR
				1		
.07483	2.5	1	3	.187	ð	.4
.06276	2.5	1	6	.157	0	.4
.01544	2.5	1	1	.039	0	.4
.02201	2.5	1	19	.055	0	.4
.93400	16.0	1	2	14.944	0	.4
.01892	16.0	1	3	.303	0	.2
.08761	10.0	1	1	.876	0	2
2.285	6	1	5	13.710	0	.4
.2490	2.5	1	n	.622	0	.4
.1135	2.5	1	108	.284	0	.4
.31536	2.5	1	9	.788	0	.4
.25610	2.5	1	26	.640	0	.4
.05606	. 2.5	1	4	.140	0	.4
.01016	2.5	1	29	.025	0	.4
						1
}						
			}		ļ.	
	.06276 .01544 .02201 .93400 .01892 .08761 2.285 .2490 .1135 .31536 .25610	.06276 2.5 .01544 2.5 .02201 2.5 .93400 16.0 .01892 16.0 .08761 10.0 2.285 6 .2490 2.5 .1135 2.5 .31536 2.5 .25610 2.5	.06276	.06276       2.5       1       6         .01544       2.5       1       1         .02201       2.5       1       19         .93400       16.0       1       2         .01892       16.0       1       3         .08761       10.0       1       1         2.285       6       1       5         .2490       2.5       1       11         .1135       2.5       1       108         .31536       2.5       1       9         .25610       2.5       1       26         .05606       .2.5       1       4	.05276       2.5       1       6       .157         .01544       2.5       1       1       .039         .02201       2.5       1       19       .055         .93400       16.0       1       2       14.944         .01892       16.0       1       3       .303         .08761       10.0       1       1       .876         2.285       6       1       5       13.710         .2490       2.5       1       11       .622         .1135       2.5       1       108       .284         .31536       2.5       1       9       .788         .25610       2.5       1       26       .640         .05606       2.5       1       4       .140	.06276       2.5       1       6       .157       0         .01544       2.5       1       1       .039       0         .02201       2.5       1       19       .055       0         .93400       16.0       1       2       14.944       0         .01892       16.0       1       3       .303       0         .08761       10.0       1       1       .876       0         2.285       6       1       5       13.710       0         .2490       2.5       1       11       .622       0         .1135       2.5       1       108       .284       0         .31536       2.5       1       9       .788       0         .25610       2.5       1       26       .640       0         .05606       2.5       1       4       .140       0

Table 6-6. On-Equipment Scheduled Maintenance, 4.5-Year System

	Ì		CONSUMABLES
i	1		
2	1	8	0
e1 2	171 Hel.	545.83	103 galclea ing agent 13,338 gal. deionized wat
1	1	12	0
1	1	1	0
2	3	96	0
		1	
1	1	98	0
1	1	16	0
1	1	4	0
1	1	8	0
3	1	540	0
2	4	200	0
2	2	64	0
2	1	32	0
2	1	32	0
	1		

Table 6-7. On-Equipment Corrective Maintenance, 6.5-Year System

ITEM	F/R 10 <sup>-6</sup>	HTTR	CREW SIZE	POPULA- Tion	ANNUAL MANHOURS	INITIAL SPARES	ANNUAL REP. SPARES	DISCARD FACTOR
COLLECTOR SUBSYSTEM:			Ì			1		
Power Cables	.108	1.5	2	139 sets	.174	2 sets	.058 sets	1.0
Control Cables	.108	1.5	. 2	139 sets	.174	2 sets	.058 sets	1.0
Heliostat Controller	5.79	2.2	2	134	13.181	2	.150	.05
100	9.74	2.2	2	· 5	.827	2	.009	.05
Motor, Elev. and Az.	2.0	1.9	2	278	8.157	2	.107	.05
Harmonic Drive	1.65	4.0	4	139	14.168	2	.044	.05
Linear Actuator	2.94	2.2	2	139	6.942	2	.079	.05
Optical Encoder, Az.	1.35	2.7	2	278	7.825	2	.072	.05
Optical Encoder, Elev.	1.35	1.1	2 .	417	4.782	2	.109	.05
Pedestal	0.1	1.0	2	139	.244	0	0	0
Structure	0.5	1.5	2	139	1.826	0	0	0
Mirror Module -	6.0/Hel.	2.0	2	139	29.223	2	7.306	1.0
Storage Motor	2.0	1.9	2	139	.174	2	.002	.05
Storage Linear Actuator	2.94	2.2	2	132	.297	2	.003	.05
Field Control Cables	.108	2.5	2	139 sets	.290	2 sets	.058 sets	1.0
Field Power Cables	.108	2.5	2	139 sets	.290	2 sets	.058 sets	1.0
Az. Limit Switch	1.87	2.0	2	278	8.029	2	2.007	1.0
Elev. & Stor. Limit Swit	h 1.87	1.1	2	556	8.832	2	4.014	1.0
Circuit Breaker & Switch	1.0	1.6	2	139	1.717	2	.537	1.0
HAC/Field Control Cables	.108	2.5	2	5 sets	.010	1 set	.002 sets	1.0
HAC/field Power Cables	.108	2.5	2	5 sets	.010	1 set	.002 sets	1.0
Absorber	1.6	14 .	4	1	7.850	0	0	0
Absorber Support Struc.	1.0	10	4	1	.350	0	0	0
Absorber Door	1.0	. 8	4	1	.280	0	0	0
Absorber Piping	1.0	12	4	1	.420	0	0	0
Vent Valve	*5.23/d.1.72/ hr	5.2	2	1	. 109	1	.001	.05

<sup>\* 1</sup> domand/week

Table 6-7. On-Equipment Corrective Maintenance, 6.5-Year System

Page 2 of 3

ITEN	F/R 10 <sup>-6</sup>	MITR	CREW SIZE	POPULA- Tion	ANNUAL MANHOURS	INITIAL SPARES	AHNUAL REP. SPARES	DISCARD FACTOR
COLLECTOR SUBSYSTEM: (Con	1 1							
Relief Valve	10	4.5	2	1	.347	2	.002	.05
Trace Heating	10	20	· 2	1	1.544	0	o	0
Insulation	1.0	10	2	1	.077	0	o	0
Hand Valves	0.1	4.5	2	2	.006	1	o	.05
Sensors	1.0	4.0	2	20	.618	) set	.077	1.0
Motor (Door)	2.0	3.0	2	1	.001	1	o	.05
ENERGY STORAGE SUBSYSTEM:								
Hand Valves	0.3	4.5	2	4	.042	1	0	.05
Check Valves	4.0	4.5	2	1	.139	1	.001	.05
Regulator	18.0	5.7	2	1	.792	1	.003	.05
Sensor	1.0	3.0	2	10	.232	1	.039	1.0
Relief Valves ~	10.0	4.5	2	1	.350	1	.002	.05
Heaters	0.4	10.0	2	10	.008	1	o	0
Tanks	1.0	10.0	2	1	.175	1	0	0
ENERGY TRANSPORT SUBSYSTEM:							~	
Control Valves	6.46	5.7	2	3	.853	2	.004	.05
Remote Valves	+5.23/d, 1.72/ hr.	5.2	2	7	.761	2	.004	.05
Check Valves	4.0	4.5	2	1	.139	1	.001	.05
Hand Valves	0.3	4.5	2	25	.261	1	.001	.05
Pumps	1000/d, 30/hr	9.7	2	2	18.120	2	.047	.05
Sensors	1.0	3.0	2	5	.116	1	.019	1
Heat Exchangers	1.8	10.0	2	3	.378	1	0	.02
lleaters	10.0	20.0	2	1	3.504	2	.002	.02
Mixer Tank	1.0	10.0	3	1	.263	0	0	0

Table 6-7. On-Equipment Corrective Maintenance, 6.5-Year System

Page 3 of 3

ITEM	F/R 10 <sup>-6</sup>	MTTR	CREW SIZE	POPULA- TIOH	ANNUAL MANHOURS	INITIAL SPARES	AHHUAL REP. SPARES	DISCARD FACTOR
POWER CONVERSION SUBSYSTE	1 1							
Radial Turbine	102.0	40.0	3	1	42.889	0	٥	0
Generator	80.0	40.0	- 3	1	33.638	٥	٥	٥
Condensor	1.0	10.0	3	i	0,105	0	٥	0
Tank	1.0	10.0	3	7	.736	0	0	0
Deaerator	1.0	10.0	3	1	0.105	0	٥	٥
Pump	1000/d, 30/hr.		2	6	53.195	2	.137	.05
Control Valve	6.46	4.7	2	15	3.187	2	.017	.05
Hand Valve Type 1	0.3	3.5	2	149	1.096	2	.002	.05
Hand Valve Type 2	0.1	3.5	2	37	.091	1	.001	.05
Pressure Sensor	1.0	2.0	2	19	.266	2	.067	1.0
Level Sensor -	1.0	2.0	2	19	.266	2	.067	1.0
Relief Valve	10.0	3.5	2	18	4.415	2	.031	.05
Remote Valve	5.23/d, 1.72/h	4.2	2	31	2.565	2	.015	.05
Flow Meter	12.0	3.5	2	2	0.589	2	.084	1.0
Level Heter	1.0	2.0	2	2	0.028	1	.007	1.0
lleat Exchanger	1.8	10.0	2	δ	.757	0	0	0
Check Valve	4.0	4.5	2	15	1.892	2	.010	.05
Cooling Tower Structure	1.0	10.0	2	1	0.175	0	0	o
Cooling Tower Tanks	1.0	10.0	3	3	0.788	0	0	0
3-Way Valves	5.23/d,1.72/hr	4.7	2	12	1.111	2	.006	.05
Temperature Sensor	1.0	2	2	4	.098	2	0	1.0
* 1. damas d/day								
* 1 demand/day ** 2 demands/day								

Table 6-8. Off-Equipment Repair, 6.5-Year System

Page 2 of 2

1TEM	ANNUAL FREQUENCY	TASK HOURS	CREW SIZE	POPULA- TION	SITEL F	MANHOURS ACTORY	REPAIR PARTS FACTOR
NERGY TRANSPORT SUBSYSTEM:							
Control Valves	.07483	2.5	1	3	.187	0	.4
Remote Valves	.07322	2.5	1	7	.183	0	.4
Check Valves	.01544	2.5	1	1	.039	0	.4
Hand Valves	.02896	2.5	1	25	.072	0	.4
Pumps .	.93400	16.0	1	2	14.944	6	.4
Heat Exchangers	.01892	16.0	1	3	.303	0	.2
lieaters	.08761	10.0	1	1	.876	0	<sub>.</sub> .2
WER CONVERSION SUBSYSTEM:							
Pump	2.742	6	1	6	16.452	O	.4
Control Valve	.3390	2.5	1	15	.847	0	.4
Hand Valve Type 1	.15663	2.5	1	149	.392	0	.4
Relief Yalve	.63072	2.5	1	18	1.577	0	.4
Remote Valve	.30535	2.5	1	31	.763	0	.4
Check Valve	.21024	2.5	1	15	.526	0	.4
Hand Valve Type 2	.01296	2.5	1	37	.632	Q	.4
3-Way Valves	.11820	2.5	1	12	.295	0	.4
							Ì
÷		1		1			į

Table 6-9. On-Equipment Scheduled Maintenance, 6.5-Year System

ITEM	ANNUAL FREQUENCY	TASK Hours	CREW SIZE	POPULA- TION	ANNUAL Manhours	ANNUAL CONSUMABLES
COLLECTOR SUBSYSTEM:						
Heliostat Field Corrosion/Structural Inspection	1	4	2	1	8	0
Mirror Hodules' Cleaning	12	.133/ile1	2	139 Hel.	443.7	83 gal. clea ing agent 10,842 gal. deionized wat
Receiver Tower Leak/Corrosion Inspection	12	1	1	1	12	0
MERGY STORAGE SUBSYSTEM:			,			
Visua) Inspection for Leaks/Corrosion (Includes Energy Transport Subsystem Components)	1	1	1	1	1	0
MERGY TRANSPORT SUBSYSTEM:						
Heat Exchanger Cleaning	1/3 years	48	2	3	96	0
CHER CONVERSION SUBSYSTEM:						
Turbine/Generator Oil Check	49	2	1	1	98	0
Turbine/Generator Trip Test, Gen. Winding Inspect.	4	4	1	1	16	0
Turbine/Generator Stop Valve, Gear Teeth Check	2	2	1	1	4	0
Turbine/Generator Oil System, Valves, Bearings Check	1	8	1.	1	8	0
Turbine/Generator Vibration Test, Overhaul	1	180	3	1	540	0
Chem. Feed Tanks' Replenishment	25	1	2	4	200	a
Heat Exchanger Cleaning	1/3 years	48	2	6	192	0
Condensor Cleaning	1/3 years	48	2	1	32	0
Deaerator Cleaning	1/3 years	48	2	1	32	0
	: 					1

Table 6-10. Maintenance Support Equipment

Equipment Item	Function
Mobile Crane, Linkbelt HC-138, 65 Ton	Used to position tower structure, absorber, energy storage tanks, heliostat pedestals and heliostat reflector panels for removal and replacement or component repair.
Mini-Cletrack Trencher- Bulldozer	Dig and cover heliostat field cable trench.
Portable Control Unit	Operate individual heliostat for checkout and troubleshooting.
Service Link 1D22779	Secure reflector during elevation drive replacement.
Pedestal Leveling Fixture 1D22761	Level heliostat pedestal to foundation interface.
Mirror Panel Lifting Sling	Remove and replace mirror panel.
Forklift, Five Ton	Move and position heavy equipment.
Washing Truck	Transport cleaning solution and rinse water.
Welding Equipment	For structural installation and repair of tower, absorber, heliostat structure, and piping.
One-Half Ton Pickup Trucks (2)	Movement of workers and materials.

# 6.2.2 Scheduled Maintenance

Scheduled maintenance requirements are summarized in Tables 6-3, 6-6, and 6-9. Particular attention has been given to reducing scheduled maintenance wherever possible. Periodic inspections include visual checks of each subsystem for corrosion, weathering, structural integrity, breakage and cracks, condition of seals and bonding, fluid leaks, and audio evidence of malfunctions.

Cleaning of mirror modules involves a truck containing a cleaning agent in solution, and deionized water rinse. A rate of 8 minutes per heliostat was



identified. The frequency of reflector cleaning is very site-dependent, seasonal, and weather dependent. MDAC has chosen a 1-month interval for cleaning as representative of long-term average cleaning rates.

Periodic flushing/cleaning of the many heat exchanger-type vessels throughout the power conversion subsystem has been identified. Requirements were defined using previous experience with similar components subjected to similar environments, with their associated scaling/penetration rate data.

The turbine/generator requires special attention due to its criticality to system operation. Requirements were developed from supplier data. These include periodic lubrication and visual inspection of critical, stressed parts, and a yearly overhaul. Periodic servicing of plant control subsystem hardware will be accomplished through a service maintenance contract with the supplier.

# 6.2.3 Unscheduled Maintenance

The on-equipment unscheduled maintenance tasks and maintenance manhours per task for each subsystem are summarized in Tables 6-1, 6-4, and 6-7. The estimated elapsed maintenance time and crew sizes are also indicated. Task elements considered include fault isolation, access time, component removal and replacement, and test and checkout time after fault correction. Certain items requiring on-equipment structural repair also appear on this table. Consideration will be given to night-time repair for such items, based on trading economy vs availability.

The tables summarize the on-equipment maintenance manhour requirements per year based on the predicted maintenance actions per year and the task manhours. The equipment quantities per site and the failure rates as derived from the reliability analyses are provided for reference. Discard factors for each item are included in the tables. These represent the percentage of failed, removed components that are judged not economical to repair.

The individual component failure rates or mean-time-between-failure estimates were obtained largely from historical data on other but similar systems.

This is described more fully in Section 6.



Off-equipment unscheduled maintenance consists of fault isolation and repair/overhaul of removed components, at the site or at the factory. The heliostat controllers, field controllers, and the harmonic drives would be repaired at the factory. These data are detailed in Tables 6-2, 6-5, and 6-8.

# 6.2.4 Spares and Repair Parts

A preliminary spares analysis was conducted based on the hardware configuration and the mean-time-to-repair. Results of this analysis to identify spare LRU quantities are included in the tables described above. Repairable LRUs, upon failure, are removed from the system, placed in the repair cycle, and subsequently returned to spare stock inventory. Initial spares quantity for these items is the sum of the pipeline quantity and a 30-day contingency supply. The quantity is equal to the maximum number of items in the repair pipeline at any given time and is based on the failure rate and the repair cycle time. A repair cycle time of one month is projected. The 30-day contingency quantity is equal to the number of predicted failures in a 30-day period, and provides a cushion in the event of delays in repair or delivery; as well as providing for a nonlinear failure rate, over time. The initial spares quantity will be procured and stocked at the appropriate repair location when the first year of operation begins.

The discard factor represents the number of failures which result in the LRU being discarded instead of repaired, primarily due to extensive damage. The product of the total number of failures per year and the discard factor equals the number of replacement LRUs to be procured at the beginning of the second and subsequent years.

# 6.2.5 Consumables

A list of consumables appear as Table 6-11. These consist mainly of chemical solutions and deionized water for cleaning or for heat transfer fluid chemistry maintenance purposes.



Table 6-11. Consumables

Item	Quantity per Year	Remarks
Deionized water		
3.5-Year 4.5-Year 6.5-Year	16,926 gal 13,338 gal 10,842 gal	Mirror cleaning
Cleaning agent		
3.5-Year 4.5-Year 6.5-Year	130 gal 103 gal 83 gal	Mirror cleaning
Gasoline for cleaning trucks	312 gal	
Gasoline for pickup trucks	2,496 gal	
Cooling tower makeup water	6,453 acre-ft	
Boiler makeup water	34,900 gal	
Cooling tower H <sub>2</sub> SO <sub>4</sub>	550 gal	
Cooling tower sodium hypochlorite	620 gal	
Hydrazine	1.5 to 10 lb	
Cooling tower scale inhibitor	75 to 220 1b	
Amine	75 gal	
HC1	267 gal	
Caustic soda	1,700 lb	
Powdered resin	60 1b	

# 6.3 MAINTENANCE EQUIPMENT AND FACILITIES

# 6.3.1 Maintenance Support Equipment

Equipment used for initial installation of various subsystems will be retained for subsequent use during periodic and corrective maintenance where practical.



Periodic and corrective maintenance of the small power system will be performed on-site whenever possible. Standard test equipment and tools will be provided for checkout, calibration, and repair of instruments, valves, heating elements, and gages.

#### 6.3.1.1 Concentrator Subsystem

Special equipment for the concentrator subsystem is as follows:

- A. Reflector Panel Washing Truck For transporting cleaning solution and rinse water, and reflector washing operations.
- B. Mirror Panel Lifting Sling For removal and replacement of mirror panels.
- C. Portable Control Unit For operating individual heliostats during checkout and troubleshooting.
- D. Service Link For securing reflector during elevation drive replacement.

Portable work platforms and ladders will be required for inspection and servicing of heliostat components. Sufficient electrical outlets should be available for power tools and for lights to be used during night maintenance operations.

#### 6.3.1.2 Receiver and Tower Subsystems

A crane and handling fixture will be brought on-site if replacement of the absorber unit is required. Work platform with protective rails will be required for inspection and repair.

Standard hand-tools, power hacksaw or pipe cutter, welder, and paint spray equipment will be provided for structural and flow line repairs.

# 6.3.1.3 Energy Storage, Energy Transport, and Power Conversion Susbystems

A crane will be brought on-site for lifting storage tanks, pumps, or other major components requiring replacement. A source of compressed air will be required for pneumatic tools.



# 6.3.2 <u>Facilities</u>

A small service room, located in the main site facility building, will be used for minor assembly, checkout, and repair operations. Small hand-tools and standard electronic checkout/calibration equipment will be stored in the service room. Commercially available hoists, slings, and portable work platforms will be provided.

# 6.4 SAFETY ASPECTS (MAINTENANCE)

The general safety requirements during maintenance will be controlled by the federal OSHA requirements (Title 29, Chapter XVII, Part 1910), applicable state and local requirements, and solar specific internal maintenance procedures. These requirements are detailed in Section 4.1.3.

Special consideration will be necessary for the maintenance of the Hitec system to prevent human contact with the hot fluid. This will consist of specific maintenance procedures and the control of leaks by pipe integrity and control of the path of the fluid when leaks occur. Salt handling procedures are required to prevent injury to humans during draining and filling the system.

The major solar specific safety problem will involve the concentrated solar energy from reflected sun light from the heliostats. Specific procedures will be required to prevent potential eye damage during mirror washing and heliostat maintenance. Also, specific maintenance procedures will be required to prevent human injury while working on the heliostats. These potential injuries could come from moving mechanisms, falling down elevated work platforms and hoists. Maintenance procedures will include provision to disable any heliostat from remote control while maintenance is performed.

#### 6.5 SECTION 6 REFERENCES

6-1. "Report on Equipment Availability for the Ten Year Period, 1967-76" Edison Electric Institute, Report No. 77-64.



# Section 7 DEVELOPMENT REQUIREMENTS

The primary objective of this task was to assess the development status of the subsystems and components of the preferred system concepts and determine the extent of research and development requirements to bring each system to maturity. The preferred system concepts have been identified in Volume II, Section 3.4, and described in Section 4 of this volume. This section reviews the MDAC approach to EE No. 1 development, key technology issues related to each major subsystem, the criticality of these issues, and corresponding development test requirements. These development test requirements would have formed the basis for the detailed Phase II and III development plans and costs.

#### 7.1 DEVELOPMENT PROGRAM OBJECTIVES AND APPROACH

As defined by JPL, the first small power system engineering experiment (EE No. 1) will be conducted in three phases as described below:

<u>Phase I</u> — Phase I includes the investigation of various system concepts, the selection of preferred approaches, the conceptual design and cost studies on these preferred approaches, and the preparation of Phase II program plans.

Phase II — Phase II consists of the preliminary and detailed design of the recommended preferred concept, the development testing of components or subsystems, and the preparation of Phase III program plans.

Phase III — Phase III consists of subsystem fabrication, plant construction, installation, testing and evaluation of the total experimental plant.

Phase I is the current 10-month contracted study effort which will end in early May 1979. Following a short interval, Phase II will be initiated. The time interval of Phase II varies (8, 18, 42 months) for three different programs (3.5-, 4.5-, and 6.5-year programs which represent the time interval from the start of Phase I to the operational startup of the experimental



plant). One month after Phase II is completed, Phase III will be initiated. Phase III is a 34- to 36-month phase in which testing of the experimental plant will begin from 22 to 24 months after Phase III go-ahead. This startup time interval is only a suggested value by JPL — other startup time intervals can be recommended provided adequate supporting rationale is provided.

The schedule for these three startup programs is summarized in Figure 7-1. JPL has nominally selected the 4.5-year startup program as the baseline case for planning purposes. Phase II development testing activities will require a normal sequencing of tasks which include test article design, fabrication, test (including installation and checkout), test evaluation, and reporting. In addition, test facility and instrumentation preparation and procurement of long-lead-time items must be phased into the overall planning.

Ample time is allowed in the 4.5- or 6.5-year programs (18 and 42 months, respectively) to complete significant development testing. However, the 3.5-year program, which only permits an 8-month Phase II period, virtually rules out the Phase II development testing of any new component or subsystem. Existing hardware and operational techniques must be used with minimal modifications. Proven technology and performance techniques must be utilized and only verified during Phase II. This has been the MDAC basic approach in the selection of the preferred concepts for the 3.5-year program in order to minimize program risks, as reviewed in Volume II, Section 3.4.

For the 4.5-year startup program, an 18-month Phase II test period has been specified by JPL. This will permit limited technology development and more extensive modifications of existing hardware and proven design/operational practices. The 6.5-year startup program permits a 3.5-year (42 month) Phase II testing period. For this program, the use of advanced subsystems and design/operational techniques becomes quite feasible. However, due to the length of this program, careful attention must be given to the supporting manloading to keep program costs from exceeding planned expenditures. Considerable periods of time with minimum manloading are expected.

The relationship of these experimental development programs with the ultimate commercial plant has been treated in Volume 13, Section 3.4.2. As reviewed



P-1:

CONCEPTUAL DESIGN

P-II:

PRELIMINARY AND DETAILED DESIGN

COMPONENT DEVELOPMENT

PROTOTYPE SUBSYSTEM ELEMENT FABRICATION AND TESTING

P-111:

PLANT CONSTRUCTION

SUBSYSTEM FABRICATION, INSTALLATION AND CHECKOUT

PLANT TESTING

Figure 7-1. Master Phasing Schedule Goals

2

in that section, the early on-line capability of the 3.5- and 4.5-year programs provides valuable subsystem and system performance and operational experience to iterate into the commercial system. The 6.5-year program requires development of virtually the full commercial system capability in EE No. 1.

In the following section, the key technology issues and development requirements are summarized for the major subsystems of the selected system concepts.

# 7.2 KEY TECHNOLOGY ISSUES AND DEVELOPMENT REQUIREMENTS

For each of the selected system concepts, an assessment has been made to determine the key technology issues, the criticality of these issues with respect to program objectives/schedules, and the resulting development test requirements. A preliminary assessment on the development status of various subsystems was made earlier in the study period in support of the selection of the preferred system concept, as reported in Volume II, Section 3.4. The information in this section represents a more detailed assessment of subsystem development issues and requirements for the selected systems. Key technology issues are identified, the timing criticality for resolution is established, and the most appropriate method of resolution is recommended. These methods of resolution include the similarity with the analyses or testing from other on-going programs, Phase II analyses, or Phase II testing. Major development and testing requirements are identified for those subsystems which have appreciable risks, as required. The development information presented in this section was to provide the basis for Phase II program planning.

# 7.2.1 <u>Concentrator Assembly</u>

The baseline concentrator assembly selected for all three program durations, as described in Section 4.2, has been based on the MDAC heliostat designs developed under several DOE contracts which include:

- A. Central Receiver Solar Thermal Power System, Phase I, Contract EY-76-C-03-1108 (Reference 7-1)\*
- B. Solar Central Receiver Prototype Heliostat, Contract EG-77-C-03-1605 (Reference 7-2)

<sup>\*</sup>References are listed at the end of the section.  $\frac{7.4}{7.4}$ 



Collector Subsystem for the 10 MWe Solar Thermal Central Reciever Power Plant, Phase 1, Contract DE-ACO3-79 ET-21006 (current)

During the design and development of these heliostats, key technology issues have been identified and considerable design analyses and testing have been conducted to resolve these issues. Based on this previous work, a number of key technology issues have been identified which are described in Table 7-1. These issues include thermal/wind distortion, solar reflectance, thermal/ operational cycling, environmental survival, adhesive compatibility, ultraviolet radiation, thermal backlighting, structural integrity, drive unit performance, mirror washing, producibility and glass cracking. All of these major technology issues have either been addressed in previous design and testing activities or will be resolved during planned tests associated with the 10 MWe project. Consequently, it has been determined that there are no unresolved technology issues that require further development testing during Phase II. For small power systems applications, minor modifications to the heliostats will be required, as outlined in Section 4.2, to facilitate site assembly and checkout, produce focusing appropriate to a small system, and adapt the heliostat controls to the plant control concept proposed for EE No. 1. However, these minor changes do not impact the technology issues and, consequently, no development testing is necessary for the heliostats. These facts would have greatly enhanced the feasibility of this experiment with respect to system reliability, development risk, commercialization and program costs.

#### 7.2.2 Receiver Assembly

The principal element of the receiver assembly is the absorber unit which consists of small constant diameter tubes configured in a spiral pattern to form a conical cavity through which the heat transfer fluid is circulated. This absorber unit must absorb the heat from the reflected solar radiation and transfer the energy into the heat transfer fluid, which is a heat transfer salt (HTS or Hitec). This media can operate over a wide temperature range (from 149°C [300°F] to 538°C [1,000°F]) without breaking down or gasifying. A description of the receiver subsystem and its operating characteristics are given in Section 4.3.

Table 7-1. Technology Issues - Concentrator Assembly (Page 1 of 2)

<b>-</b>		Resolution*	
Technology Issue	3.5 Yr	4.5 Yr	6.5 Yr
1. Thermal/Wind Distortions - Ability to minimize focusing errors caused by distortions of the mirror surface and support structure from combined thermal expansion and wind loads.	S,A	S,A	S,A
2. Solar Reflectance - Efficiency of solar transmittance and reflectivity as a function of glass thickness, curvature, chemistry (iron content), silver deposition and aperture angles.	S,A	S,A	S,A
3. Thermal/Operational Cycling - Ability of subsystem to survive thermal and operational cycling over a 30-year life (approx 10,000 cycles) without delamination or permanent distortion.	S,A	S,A	S,A
4. Environmental Survival - Ability to survive continual exposure to extreme environmental conditions (temperatur moisture condensation, wind, dust, rain, hail, frost, snow).	s,A re,	S,A	S,A
<ol> <li>Adhesive Compatibility - Ability to laminate the glass mirrors, styrofoam and steel backing with suitable adhesives.</li> </ol>	S,A	S,A	S,A
6. Ultraviolet Radiation - Ability of the foam core to withstand ultraviolet radiation without damage or degradation.	S,A	S,A	S,A

<sup>\*</sup>Principal approach to resolution

S - Similarity to existing/planned equipment, programs or tests A - Analytical verification during Phase II T - Testing during Phase II

Table 7-1. Technology Issues - Concentrator Assembly (Page 2 of 2)

		F	Resolution*	
•	Technology Issue	3.5 Yr	4.5 Yr	6.5 Yr
7.	Thermal Backlighting - Ability to operate and survive in the presence of backlighting from adjacent mirrors.	S,A	S,A	S,A
8.	Structural Integrity - Verification of strength, deflection, creep and vibrational frequencies of structural elements and foundation under normal operating and design loadings.	S,A	S,A	S,A
9.	Drive Unit Performance - Verification of drive unit performance considering slew rates, accuracies, travel, operating loads, stowage loads, back lash, minimum resonant frequency, back drive characteristics, wear, and 30-yr life.	S,A	S,A	S,A
10.	Mirror Washing - Validation of reflector washing requirements and timelines without serious degradation of reflectivity or structural integrity.	S,A	S,A	S,A
11.	Glass Cracking - Ability to prevent glass cracking at the edges due to nicks or transient, differential in-plane temperatures.	S,A	S,A	S,A
12.	Producibility - Ability to fabricate, assemble, transport and install the subsystem using the design techniques, materials and procedures specified.	S,A	S,A	S,A

<sup>\*</sup>Principal approach to resolution

S - Similarity to existing/planned equipment, programs or tests A - Analytical verification during Phase II T - Testing during Phase II

In order to minimize development risks, especially for the 3.5-year startup program, the designs of the receivers have been slightly varied for each startup program so as to keep heat flux and operating temperatures within prescribed levels. Receiver design criteria for the three programs are summarized in Table 7-2. Since the 3.5-year program only permits limited Phase II testing as outlined in Section 7.1, the maximum bulk temperature and heat flux limits have been set at 454°C (850°F) and 500 kW/m², respectively, which is conservative compared with current technology for fossil-fired Hitec heaters. By using ample structural and thermal design margins, heat transfer tests will not be necessary for the 3.5-year program. For the longer (4.5-and 6.5-year) programs, more development time is available for analyses and testing and, consequently, high temperatures and heat flux limits can be set which will permit better design optimization, as indicated on the table.

The major technology issues for the proposed receiver subsystem concepts are summarized on Table 7-3. These issues include heat flux capabilities, flow control, thermal stresses, panel/tube life, fill and drain capabilities, trace heating effectiveness, insulation effectiveness, environmental survival, and producibility. Heat transfer and thermal stress tests are not necessary for the 3.5-year program in which the operating temperature range of Hitec is kept to relatively low levels. All other technology issues can also be resolved by either similarity to other existing or planned programs and equipment, or by analytical verification during Phase II based on experimentally derived factors. As shown on Table 7-3, additional testing is recommended for the 4.5- and 6.5-year programs that reflect the higher heat flux and operating temperatures.

The operational feasibility of the receiver can be substantiated without development testing by analogous Hitec heaters of the type shown in . Figure 7-2. This represents a state-of-the-art Hitec heater utilizing helical coils in gapless parallel arrangement. Fired heaters of this sort using various heat transfer media have been manufactured since 1937. Similar equipment has been installed and operated successfully in a variety of process industries — over 1,000 installations throughout the world. Thus, the design and operations of the Hitec cooled receiver using coiled tubes and staying within established heat flux and temperature regimes are considered to be state-of-the-art.



Table 7-2. Receiver Design Criteria

Development Program Duration	3-1/2 Years	4-1/2 Years	6-1/2 Years
Phase II Scope	Limited tests (or none)	Heat transfer and full-scale tests	Development and full-scale tests
Consequences of Phase II Scope	Current technology for heat transfer and flux	Limited advances in technology	Allows more technology advances
Maximum Bulk Temperature Limit	454°C (850°F)	510°C (950°F)	538°C (1,000°F)
Heat Flux Limit	500 kW/m <sup>2</sup>	800 kW/m <sup>2</sup>	1,000 kW/m <sup>2</sup>
Structural and Thermal Design Margins	Ample, based on current technology	Allows design optimization	Allows more complete optimization

Table 7-3. Technology Issues - Receiver Assembly (Page 1 of 2)

			Resolution,	k
	Technology Issue	3.5 Yr	4.5 Yr	6.5 Yr
1.	Heat Transfer Capabilities - Ability to accept peak heat flux and to efficiently heat the receiver fluid to operating temperatures at nominal flow rates and insolation conditions.	S,A	Т	T
2.	Flow Control - Ability to operate and control the assembly over the total power/flow range (including start, stop, and intermittent (passing cloud cover) conditions without serious performance degradation, excessive flow discharge temperatures, or flow stability problems.	S,A	Т	Т
3.	Thermal Stresses - Ability of the absorber tubing and piping to expand and contract so as to prevent undue stress buildup as a result of asymmetrical solar heating.	S,A	Т	T
4.	Panel/Tube Life - Ability of the absorber to survive thermal cycling, corrosion and environmental conditions over a 30-year life (approx 10,000 cycles; 100,000 hours).	S,A	S,A	S,A

<sup>\*</sup>Principal approach to resolution:

S - Similarity to existing/planned equipment, programs or tests A - Analytical verification during Phase II T - Testing during Phase II

Table 7-3. Technology Issues - Receiver Assembly (Page 2 of 2)

			Resolution	*
	Technology Issue	3.5 Yr	4.5 Yr	6.5 Yr
5.	Fill and Drain Capabilities - Ability to adequately drain the receiver assembly for necessary maintenance/repair and enable refill without unacceptable freeze-up or thermal shock to subsystem components.	S,A	S,A	S,A
6.	Trace Heating Effectiveness - Ability to adequately heat all subsystem elements throughout non-operating periods to prevent localized freezing (of Hitec or HTS), particularly in the absorber tubing and valves.	S,A	S,A	S,A
7.	Insulation Effectiveness - Ability of the selected insulation to perform satisfactorily through expected thermal cycling up to peak heat loads.	S,A	S,A	S,A
8.	Environmental Survival - Ability of the total receiver subsystem to survive extreme environmental conditions (temperature, moisture condensation, wind, dust, rain, hail and snow).	S,A	S,A	S,A
9.	Producibility - Ability to be fabricated, assembled, transported and installed using the design techniques, materials, and procedures specified.	S,A	S,A	S,A

<sup>\*</sup>Principal approach to resolution:

S - Similarity to existing/planned equipment, programs or tests A - Analytical verification during Phase II T - Testing during Phase II

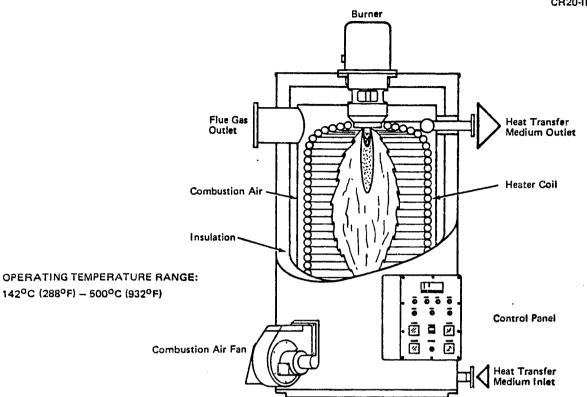


Figure 7-2. Fired Hitec Heater State-of-the-Art

Other related experience includes the use of the French Odeillo 1-MWt solar facility which has been reconfigured to supply more than 50 kW to an electric grid. The receiver for this facility utilizes spiral tubes in a cylindrical cavity with oil (similar to Therminol-66) as coolant.

# 7.2.3 Tower Assembly

The tower assembly is an open-frame steel structure supported by guy wires. Assembly elements include the supporting foundations, a service elevator, working platforms, access provisions, a heliostat tracking device, line supports, instrumentation and electrical interconnects, lights and lightning provisions. These elements are described in Section 4.4. The tower and all of its elements are based on standard start-of-the-art construction practices. Consequently, there are no technology issues that require development testing in Phase II for any of the EE No. 1 programs.



# 7.2.4 Energy Storage Subsystem

The energy storage subsystem includes the storage tanks, supporting foundations, connecting lines and valves, insulation, heaters, and storage media. These elements were described in Section 4.5. As described in Volume II, in order to minimize development risks, a two-tank system has been proposed for the 3.5- and 4.5-year programs whereas for the 6.5-year program a single dual-media (taconite/salt) tank has been proposed.

The major technology issues and principal approaches to the resolution of these issues for these thermal storage concepts are summarized on Table 7-4. These issues include flow stability and control, thermocline feasibility, fluid/material compatibility, tank bed warmup, tank stresses, and producibility. For the two-tank approach, no testing is required for either the 3.5- or 4.5-year programs because the two-tank design approach is very simple; standard design practices and materials are used; and temperatures are not excessive. For this approach, all technology issues can be resolved in Phase II by analytical verification and by similarity to existing equipment, procedures, and testing.

As can be noted, most of the technology issues and the Phase II testing requirements are related to the dual-media thermocline concept which has been proposed for only the 6.5-year program. Ample development time exists to properly test this approach. Considerable related test information and valuable operating experience will also be available from the 10 mWe Barstow pilot plant in which a dual-media thermocline storage system has been developed utilizing crushed granite and Caloria.

# 7.2.5 Energy Transport Subsystem

The energy transport subsystem includes all transport elements associated with the Hitec/HTS energy loop, including piping, expansion joints, piping support structures and foundation, insulation, trace heating, pumps, and flow control valves. These elements are described in Section 4.6. Energy transport systems for Hitec are well-known and widely used throughout many industries. All of these elements proposed for EE No. 1 are based on existing state-of-the-art equipment and practices. There are no critical technology issues



Table 7-4. Technology Issues--Energy Storage Subsystem

		Resolution*			
	Technology issue	3.5 year	4.5 year	6.5 year	
1.	Flow Stability and Control - Ability to efficiently receive, store and deliver heated fluids over the full range of expected operating conditions including steady-state operations, startup and shutdown cycles, and transient/intermittent.	S,A	S,A	T	
2.	Thermocline Feasibility - Ability to develop and maintain a thermocline in a dual-medium storage tank under steady state fluid flow conditions, including the effects of natural heat loss at the tank walls.		<b>- -</b> 44	S,A	
3.	Fluid/Material Compatibility - Long term compatibility of the heat transfer fluid with the materials of tank construction or thermal storage rocks considering the effects of fluid/metal/rock chemical interactions, corrosion, physical property changes, residue deposits or surface coatings, and possible degradation of thermal storage efficiencies or flow control.	S,A	S.A	T	
4.	Tank Bed Warmup - Ability of the tank heaters to adequately warm heat transfer fluids to operating temperature levels compatible with startup and intermittent pumping and flow requirements.	s,A	S,A	S,A	
5.	Tank Stresses - Ability of the storage tank to withstand the stresses induced by the repeated thermal or pressure cycling and the interactions between the tank walls and rock bed from rock settling and packing.	<b></b> ,		S,A	
6.	Producibility - Ability to be fabri- cated, assembled, transported and installed using the design techniques, materials and procedures specified.	S,A	S,A	S,A	

<sup>\*</sup>Principal approach to resolution:
S - Similarity to existing/planned equipment, programs or tests
A - Analytical verification during Phase II
T - Testing during Phase II

that require development testing during Phase II for the 3.5- and 4.5-year programs. Existing off-the-shelf equipment will be used exclusively in these programs.

The high temperature binary salt used in the 6.5-year program requires qualification of materials and components for this salt mixture at the elevated temperatures. It should be noted, however, that the bottom of the temperature range selected for this program corresponds to current state-of-the-art. The on-going DOE-sponsored heat transfer salt program at Sandia, Livermore, can provide the advanced technology base for this program.

The dual-media, thermocline storage subsystem in the 6.5-year program makes the use of in-line horizontal centrifugal salt pumps preferable to the vertical submerged pump. While several pump manufacturers claim that their products have this capability, qualification of the pump should be conducted during Phase II of the 6.5-year program.

# 7.2.6 Power Conversion Subsystem

The power conversion subsystem includes several major elements including the turbine/generator assembly, the water/steam conditioning equipment (steam generator, feed-water heaters, cooling tower, condensers, water treatment, deaerator, pumps, valves), and balance of plant equipment including electrical housing and support equipment. Descriptions of these elements are given in Section 4.7. Most of the power conversion subsystem equipment is state-of-theart existing equipment which requires no development testing. The only subsystem element that will require development testing is the radial turbine selected for the 6.5-year program. As described in Volume II, in order to minimize development risks, the use of an existing axial steam turbine has been proposed for the 3.5- and 4.5-year programs. The major technology issues associated with these turbine concepts are shown on Table 7-5 and include turbine stage development, turbine efficiency, gearbox efficiency, structural integrity, transient response, startup and shutdown, and producibility.

The axial steam turbines proposed for the 3.5- and 4.5-year programs are based on existing equipment. The turbines are very similar and have maximum power



Table 7-5. Technology Issues — Turbine/Gearbox Assembly

		R	esolution*	•
	Technology issue	3.5 year	4.5 year	6.5 year
1.	Turbine Stage Development - Ability to develop a high-performance, multiple stage turbine as affected by blade design, tip clearances, pressure ratio, mass flow rate, extraction ports, and inlet/outlet steam conditions.	S,A	S,A	T
2.	Turbine Efficiency - Verification of the predicted aerodynamic expansion and thermodynamic cycle efficiencies of the baseline design over the range of expected operating conditions.	S "A	S,A	T
3.	Gearbox Efficiency - Verification of predicted gearbox efficiencies at all operating conditions.	S,A	S,A	S,A
4.	Turbine Structural Integrity - Verification of the structural integrity of turbine blades, tearings and seals over the expected power conditions up to 120 percent of design speeds.	S,A	S,A	Τ
5.	Transient Response - Ability to respond to rapid transients in turbine inlet flow conditions that can occur due to intermittent cloud passage.	S,A	S,A	S,A
6.	Startup and Shutdown - Demonstrate that startup and shutdown operations and control procedures are feasible and safe.	S,A	S,A	T
7.	Producibility - Ability to be fabricated, assembled, transported and installed using the design techniques, materials and procedures specified.	S,A	S,A	S,A

<sup>\*</sup>Principal approach to resolution
S - Similarity to existing/planned equipment, programs or tests
A - Analytical verification during Phase II
T - Testing during Phase II

ratings of approximately 2.5 MWe. For EE No. 1, these turbines will be configured to match the desired operating conditions, and no verification or qualification testing is necessary. Therefore, as noted on Table 7-5, all technology issues for the axial turbine can be resolved by analyses and similarity to existing equipment, and no Phase II development testing is required.

Radial steam turbines of the type proposed for the 6.5-year program are under development at this time by Energy Technology, Inc (ETI). For EE No. 1 application, several technology issues must be addressed in Phase II development testing, as noted on Table 7-5. The compatibility of the turbine development schedule within the 18 months available in Phase II of the 4.5-year program was marginal and therefore only considered for the 6.5-year program, as described in Volume II. ETI has several related radial development programs underway at this time. A 30-HP radial turbine program for air conditioning use has been underway since 1977 and will be tested in early 1979. A radial turbine design study has recently been initiated for NASA-Lewis for application in the 100 kWe to 5 MWe range.

# 7.2.7 Plant Control Subsystem

The plant control subsystem includes all instrumentation/sensor devices, controls, signal transmission equipment, processor/computers, control software, and control room support equipment, including data display, recording devices, and control switches. Descriptions of this equipment are given in Section 4.8. All of the plant control equipment is based on existing state-of-the-art equipment and operational practices and, consequently, there are no major technology issues that require development testing in Phase II for any of the EE No. 1 programs.

# 7.3 TEST REQUIREMENTS SUMMARY

In Section 7.2, an assessment of the technology development status has been made of each major subsystem. Important technology issues and specific methods of resolution have been identified for each major subsystem for the three startup programs. From this assessment, all recommended Phase II development testing requirements have been summarized and are listed on Table 7-6.



Table 7-6. Phase II Development Test Requirements Summary

Phase II test requirements

Subsystem/Assembly	Technology issues	3.5 Year	4.5 Year	6.5 Year
Concentrator	(None requiring Phase II tests)	acas	-	-
Receiver	o Heat transfer capabilities	-	Х	Χ
	o Flow control	-	X	Х
	o Thermal Stresses	-	X	Х
Tower	(None requiring Phase II tests)	-	-	-
Energy storage	o Flow stability and control	-	-	Х
	o Fluid/material compatibility	-	-	X
Energy transport	o Equipment qualification	-	-	X
Power conversion	o Turbine stage development	-		X
	o Turbine efficiency	-	-	X
	o Turbine structural integrity	-	•••	X
	o Startup and shutdown	-	-	X
Plant control	(None requiring Phase II tests)	-		-

As can be noted from this summary, no tests are recommended for the 3.5-year program. For the 4.5-year program, receiver tests are recommended. For the 6.5-year program, additional tests are recommended, associated with the use of a dual-media thermocline energy storage subsystem and the radial turbine.

Specific Phase II test plans were to be generated based on these test recommendations. These test plans were to include descriptions of each test, test hardware, test facilities and equipment, test operations and reporting requirements, schedules, manloading and costs. Subcontractor roles and responsibilities were also to be defined. As stipulated by JPL, these plans were to be reported separately at the end of the contract period. However, all Phase II planning efforts were discontinued prior to contract completion by direction from JPL. Consequently, Phase II plans have not been reported.



# 7.4 SECTION 7 REFERENCES

- 7-1. "Central Receiver Solar Thermal Power System, Phase I" CDRL Item 2 Pilot Plant, MDAC Report MDC G6776, October 1977.
- 7-2. "Central Receiver Prototype Heliostat CDRL Item B.4," Final Report, MDAC Report MDC G7399, August 1978.

# Appendix A SYSTEM REQUIREMENTS SPECIFICATION

#### A.1 SCOPE

This specification defines the design and performance, environmental, fabrication and installation, operational, maintenance and repair, and other system and subsystem requirements for Phase I of the first Small Power System Experiment (Engineering Experiment No. 1). Section A.3.1 contains general requirements that pertain to all subsystems, and Sections A.3.2 through A.3.8 contain specific requirements pertaining to the major subsystems. This specification will be updated, as required.

The metric system of units will be used followed by the English units in parentheses.

#### A.2 APPLICABLE DOCUMENTS

The equipment, materials, design, and construction of the Small Power System Experiment will comply with all Federal, state, local, and user standards, regulations, codes, laws and ordninances which are currently applicable for the selected site and the using utility. These will include but not be limited to the government and nongovernment documents itemized below. If there is an overlap in or conflict between the requirements of these documents and the applicable Federal, state, county or municipal codes, law, or ordinances, that applicable requirement which is the most stringent will take precedence. The following documents form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification will be considered a superseding requirement.



# A.2.1 GOVERNMENT DOCUMENTS

# Specifications

Regulations of the Occupational Safety and Health Administration (OSHA) Regulations of the California Occupational Safety and Health Administration (Cal/OSHA) - if required

The International System of Units, 2nd Revision, NASA SP-7012 Regulations of the Federal Aviation Administration
Regulations of the Civil Aeronautics Board

# Standards

MIL-STD-1472, Human Engineering Design Criteria

# Other Publications

U.S. Weather Bureau Maximum Wind Velocities, 50-year Mean Recurrence, Fastest Mile (1 Minute)

Design Handbook on Electromagnetic Compatibility (AFSC DH1-4)

Checklist of General Design Criteria (AFSC DH1-X)

Instrumentation Grounding and Noise Minimization Handbook (AFRPL-TR-65-1)

National Motor Freight Classification 100B - Classes and Rules for Motor Freight Traffic

Uniform Freight Classification 11 - Railroad Traffic Rates Rules and Regulations

CAB Tariff 96 - Official Air Transport Rules Tariff

CAB Tariff 169 - Official Air Transport Local Commodity Tariff

R. H. Graziano's Tariff 29 - Hazardous Materials Regulations of the Department of Transportation

CAB Tariff 82 - Official Air Transport Restricted Articles Tariff

#### A.2.2 NON-GOVERNMENT DOCUMENTS

#### Specifications

Additional interface specifications will be prepared as required for individual subsystems



# Standards

American National Standards Institute, B31.1, Power Piping Code Manual of Steel Construction, 7th Edition, 1974, American Institute of Steel Construction

American National Standards Institute (Y10.19-1969 and C1.1971)

Building Code Requirements for Reinforced Concrete (ACI 318-71), American Concrete Institute

National Electrical Code, NFPA 70-1975 (ANSI C1-1975)

NFPA Bulletin No. 78 (ANSI C5.1)

National Electrical Manufacturers Association Standards
National Tubular Exchanger Manufacturers Association Standards
Seismology Committee Structural Engineers Association of California
American Society of Mechanical Engineers, Boiler and Pressure Vessel
Code:

Section I, Rules for Construction and Power Boilers

Section II, Material Specifications

Section V, Nondestructive Examination

Section VIII, Unfired Pressure Vessels

Section IX, Welding and Brazing Qualifications

Uniform Building Code - 1973 Edition, Vol 1 by International Conference of Building Officials

American Society for Testing Manuals Standards



#### A.3 REQUIREMENTS

# A.3.1 General System Requirements

#### A.3.1.1 System Definition

The small power central receiver system contains five major subsystems:
(1) collector subsystem, (2) energy storage subsystem, (3) energy transport subsystem, (4) power conversion subsystem, and (5) plant control subsystem. The collector subsystem, in turn, is divided into concentrator, receiver, and tower assemblies. Brief definitions of these subsystems are described below, whereas more specific subsystem definitions and requirements are contained in Sections A.3.2 through A.3.8.

# Collector Subsystem-Concentrator Assembly

The concentrator assembly will be used to optically focus solar radiation onto a tower-mounted receiver. This subsystem is comprised of a field of tracking reflectors, called heliostats. The reflecting surface of each heliostat consists of rectangular mirrors mounted on a pedestal with azimuth and elevation drives. Each heliostat is automatically controlled by a central control unit to track the sun and continually direct the reflected sunlight onto the receiver. The heliostat field is located north of the receiver. The number of heliostats in the field vary in proportion to system power requirements and system efficiency.

# Collector Subsystem-Receiver Assembly

The receiver assembly will be used to receive the reflected solar radiation from the concentrator subsystem, absorb this radiation as thermal energy, and transfer the energy to a heat transfer fluid which is circulated through the receiver by the energy transport subsystem. The heat transfer fluid is a heat transfer salt medium consisting of the nitrates of sodium and potassium with sodium nitrite added for the 3.5- and 4.5-year programs. The principal element of the receiver, which is mounted on the top of the tower, is the



absorber unit which consists of small constant diameter pipes configured in a spiral pattern to form a conical cavity through which the fluid is pumped. The absorber unit is contained within a structural housing complete with doors, insulation, heaters, controls and instrumentation. The receiver unit faces north and is tilted downward toward the heliostat field.

# Collector Subsystem-Tower Assembly

The tower will be used to support the receiver assembly and associated energy transport equipment. The tower is an open-frame steel structure nominally 40 m (131 ft) in height supported by four or more guy wires. The tower must support receivers weighing as much as 10,000 kg (22,000 lb). Tower elements include the tower, guy wires, supporting foundations, working platforms and access provisions, service elevators, heliostat target device, instrumentation and electrical interconnects, lights, and lightning protection provisions.

# Energy Storage Subsystem

The energy storage subsystem will be used to store excess thermal energy as sensible heat during periods of high insolation for use during periods of low insolation. Elements of this subsystem include storage tanks, storage media, connecting lines and valves, insulation, heaters, intert gas blanket, and supporting foundations. For the 3.5- and 4.5-year startup programs, two tanks are used in which hot fluid is stored in one tank and cold fluid stored in the other. For the 6.5-year startup program, a single dual-media (taconite/salt) thermocline tank is used in which a large percentage of the tank volume is filled with taconite.

## Energy Transport Subsystem

The energy transport subsystem, which uses heat transfer salts as the transport media, will be used to transport thermal energy absorbed at the receiver to the thermal storage tanks and thence from the storage tanks to the power conversion subsystem steam generator. Subsystem elements include piping and expansion joints, piping support structures and foundations, insulation, trace heaters,



fluid pumps (which are located inside the thermal storage tanks for the 3.5-year and 4.5-year programs), control valves and instrumentation.

## Power Conversion Subsystem

The power conversion subsystem will be used to convert thermal energy to electrical energy and condition the power, as required. Key subsystem elements include a turbine/gearbox/generator assembly, steam generator, feed water heaters, condenser, cooling tower, water treatment, deaerator, circulation pumps, instrumentation, valves and lines and electrical plant equipment (switchgear, transformers, controls and wiring). The power conversion subsystem utilizes a water/steam fluid loop for energy conversion. High temperature/high pressure steam is produced in the steam generator which draws heat from the heat transfer salts. The superheated steam is expanded through a turbine-generator assembly to produce electrical power. The discharged steam is condensed, cooled, treated and reheated for recirculation into the steam generator. The power conditioning equipment transforms, switches, regulates and controls the electrical output of the turbine-generator assembly to ensure compatible integration into an existing electrical power transmission network.

## Plant Control Subsystem

The plant control subsystem will consist of the facilities, hardware, and software necessary for the operation and coordination of all subsystem processes, either automatically or manually under the direction of the plant operator. Subsystem elements include sensor/control equipment, signal transmission equipment, processors/computers, control software, system data display, recording and controls, and the control room/building. This subsystem will be used to monitor and control the system during startup, normal operation, intermittent operation and shutdown in a coordinated fashion while continually adjusting the heliostats, fluid flows and turbine speed to maintain safe and proper energy balances within the system.



#### A.3.1.2 Performance

# System Rated Power

The nominal value of system rated power capacity is 1.0 MWe. The system rated power of 1.0 MWe will be the maximum power delivered to the utility grid interface from the collector field only for a direct normal insolation value of 800 W/m<sup>2</sup> at solar noon at equinox at the reference plant location. The collector field must be sized so that the plant is capable of generating at least the rated power at this insolation value. To satisfy capacity factor requirements, energy storage will be required, and the field size will be increased appropriately to ensure that system rated power will be provided continuously for several hours of the day and not just instantaneously. To satisfy in-plant auxiliary power demands, system power requirements for design purposes will be increased appropriately.

# System Capacity Factor

The nominal value of system capacity factor is 0.4 on an annual basis. Capacity factor is defined as the ratio of the actual energy delivered by the solar system in a given period to the capacity rating times the same time period.

The system will generate no more than the nominal rated power of 1.0 MWe from the field of solar collectors, and up to 100% of rated capacity from storage so that the annual capacity factor is at a nominal value of 0.4. Appropriate levels of thermal energy collection and storage will be required to insure that rated power can be provided by the plant over several hours of the day such that the nominal capacity factor will be met. Insolation models are to be based on the 1976 Barstow insolation data. Barstow insolation data for three clear days during the summer and winter solstice and equinox are shown on Figure A-1 and Table A-1. Receiver coolant flow must be sized to handle energy collection capabilities as influenced by the concentrator and receiver performances. Energy storage must be sized to handle the maximum daily energy surplus.



## System Auxiliary Power

Auxiliary power will be required to operate pumps, valves, heliostat tracking, heating, instrumentation and controls, and other service equipment.

Analysis and summary of the system auxiliary loads are presented in Volume V, Section 2. A summary of the auxiliary power required during normal daily operation is presented below. The gross electrical power generation capability shall be increased from 1,000 kWe to account for these loads.

## System Auxiliary Loads

Program	3.5 Year	4.5 Year	6.5 Year
Peak Auxiliary Load	135 kWe	110 kWe	80 kWe

# System Efficiencies

System performance efficiencies should be as high as possible consistent with reliability/availability, program risk, commercialization potential, and program cost goals.

#### A.3.1.3 Environmental Conditions

The plant will be capable of operating in and surviving appropriate combinations of environmental conditions that include insolation, temperature extremes, winds and gusts, dust and sandstorms, rain, hail, snow and ice, seismic loads, and lightning, as defined in the following subsections.

#### Insolation

Barstow insolation data for 1976 collected by West Associates and analyzed by the Aerospace Corporation will be used. Representative Barstow insolation data for clear days during the summer and winter solstice and equinox, are shown on Figure A-1. The maximum rate of change of incident flux will be assumed as that which would result from the passage of an opaque cloud across an otherwise clear sky where the sharp leading or trailing edges of the shadow move across the collector field at a velocity of 20 m/s.



Table A-1. Barstow 1976 Insolation

Eq	uinox	Summ	er solstice	Wint	er solstice
Time (hr)	Insolation (W/m <sup>2</sup> )	Time (hr)	Insolation (W/m <sup>2</sup> )	Time (hr)	Insolation (W/m <sup>2</sup> )
6	0	4.8	0	7,2	0
7	630	5	200	8	635
8	820	6	635	9	830
9	910	7	805	10	920
10	950	8	890	11	955
11	960	9	930	12	965
12	970	10	955	13	960
13	965	11	970	14	925
14	950	12	980	15	835
15	905	13	980	16	600
16	825	14	970	16,8	0
17	625	15	950		
18	0	16	905		
		17	805		
		18	615		
		19	170		
		19.2	0		

#### Temperature

The plant will be able to survive, without damage, an ambient air temperature range from  $-30^{\circ}\text{C}$  ( $-22^{\circ}\text{F}$ ) to  $60^{\circ}\text{C}$  ( $140^{\circ}\text{F}$ ). The plant will be able to operate in an ambient air temperature range from  $0^{\circ}\text{C}$  ( $32^{\circ}\text{F}$ ) to  $+49^{\circ}\text{C}$  ( $120^{\circ}\text{F}$ ). Performance requirements should be met throughout the ambient air temperature range selected to be consistent with minimization of the overall cost of electricity production. Typical temperatures for a day in the spring season are tabulated in Table A-2.



Table A-2. Typical Temperature Data-Spring Season Day

Hour	Spring temperature °C(°F)
Midnight	5,6(42)
1	5.0(41)
2	5,0(41)
3	5.0(41)
4	3.9(39)
5	2.8(37)
6	2.8(37)
7	1.7(35)
8	2.8(37)
9	3.9(39)
10	6.7(44)
11	7.8(46)
12	10.6(51)
13	10.0(50)
14	11.7(53)
15	13.9(57)
16	12.8(55)
17	12.8(55)
18	10.0(50)
19	7.8(46)
20	6.1(43)
21	3.9(39)
22	2.8(37)
23	2.8(37)

### Winds and Gusts

- Survival conditions The plant (with the concentrators stowed) shall survive, without damage, winds and gusts with a maximum speed of 40.2 m/s (90 mph) from any direction in any orientation resulting from unusually rapid wind rise rates, such as severe thunderstorm gust fronts. Gust induced angles of attack up to  $10^{\circ}$  shall be considered (applicable to the vertical velocity component). A larger ( $\sim \pm 20^{\circ}$ ) variation in the direction of the horizontal component should also be included for concentrators lacking horizontal symmetry. The plant (with the concentrators in the operational position) shall survive, without catastrophic failure, winds and gusts up to 22 m/s (50 mph) in the most adverse orientation.
- Operating conditions The system must be capable of operating in a 13 m/s (29 mph) wind. Maximum operational wind speeds shall be selected based on tradeoffs between plant and energy costs. A maximum operational windspeed of 16.1 m/s (36 mph) has been established for preliminary design. Concentrator stowage will be initiated at this speed. A maximum wind rise rate of 0.01 m/s<sup>2</sup> (1.3 mph/min) shall be used in calculating wind loads during stowage. Wind velocity profile varies exponentially with height to the 0.15 power, where the reference height is taken as 10 m (30 ft).

$$v_z = v_{10m} \left(\frac{z}{10m}\right)^{0.15}$$

where:

 $V_{10m}$  = reference wind velocity at height of 10 m

0.15 = power law exponent for flat open country

Z = height in meters

 $V_{\tau}$  = mean wind velocity at height Z



The wind speed frequency at a reference height of 10 m (30 ft) shall be:

Speed (m/s)	Frequency (Percent)
0-2	¹ <b>29</b>
2-4	21
4-6	19
6-8	14
8-10	8
10-12	5
12-14	. 3
>14	<1

### Dust and Sandstorms

The plant shall survive, without damage, blowing dust comparable to the test conditions described by MIL-STD-810B, Method 510. Dust devils with wind speeds up to 17 m/s (40 mph) shall be survived without damage to the plant in the operational mode.

# Rain, Snow, Ice and Hail

The plant (with the concentrators in the stowed position) shall survive, without damage, the following environmental conditions:

- Rain: Average annual amount of 750 mm (30 in) at a maximum 24-hr rainfall rate of 75 mm (3 in)
- Snow: 250 Pascals (5  $1b/ft^2$ ) at a deposition rate of 0.3 m (1 ft) in 24 hr
- Ice: Freezing rain and ice deposits in a layer of 50 mm (2 in) thick
- Hail:

	Any Orientation	Stowed
Diameter	20 mm (3/4 in)	25 mm (1 in)
Specific Gravity	0.9	0.9
Terminal Velocity	20 m/s (65 fps)	23 m/s (75 fps)



### Seismic

The plant must survive, without structural damage or yielding, an earthquake that would produce an acceleration on the order of 0.20 to 0.25 g horizontal and vertical ground accelerations and shaking intensity of about VII to VIII on the Modified Mercalli Scale. The spectral presented in U.S. Atomic Energy Commission (Revision 1, dated December 1973) Regulator Guide 1.60 should be used as a guide. In addition, the plant must satisfy the requirements specified for Seismic Zone 3 in the Uniform Building Code. Realignment of the concentrators after an earthquake is allowed.

# Lightning

The plant shall be provided with lightning protection. Total destruction of a single collector and its controller subjected to a direct lightning strike is acceptable. Damage to a collector adjacent to a direct lightning strike should be minimized within appropriate cost-risk limits. The central controller and local controllers of collectors adjacent to a direct lightning strike must be protected or alternate control methods provided to minimize loss of collection system control.

### A.3.1.4 Operations

The experimental system shall exhibit stable, controlled and safe operations during startup, normal operation, shutdown, emergency, and intermittent operation modes.

#### Startup Mode

Solar energy collection and power conversion are two independent operating modes. System startup shall be corrdinated through the plant control subsystem. For energy collection, the heliostats shall be oriented to their predicted sun acquisition positions prior to startup using power from the network or the auxiliary source. The startup shall begin when the sun is <10° above the horizon. Fluid flow shall be initiated through the receiver unit.



The heliostats shall acquire the sun sequentially in order to control the full system powerup. Warm fluid developed in the receiver shall be recycled to the cold thermal storage tank until rated temperature and flow conditions are available. Then startup of collection mode is completed by directing the hot HTS to the hot storage tank. During startup of the power conversion mode, steam shall be introduced into the turbine at a controlled rate for turbine heatup and startup. The turbine shall be loaded and the electrical power shall be synchronized with the interconnecting power network.

### Normal Operation Mode

Normal power operation is defined as that period when the turbine-generator can operate at its design conditions. This period includes normal daytime solar operation in which the thermal energy absorbed in the receiver and transferred to the thermal storage subsystem is sufficient to produce steam at rated temperature and pressure (nominally between 9 AM and 3 PM), plus that period during which the thermal storage subsystem can provide additional stored heat to produce steam at rated conditions. The system shall produce rated power at an annual capacity factor of 0.4.

During normal daytime solar operation, all of the thermal energy collected in the receiver shall be directed to the thermal storage subsystem. The turbine-generator shall be simultaneously operated from steam produced by the thermal storage subsystem. During periods when the receiver is incapable of producing useful heat, the turbine may continue to operate from energy contained in the thermal storage subsystem.

### Intermittent Operation Mode

During periods when excessive transients in solar insolation occur due to intermittent cloud cover, fluid flow in the receiver will be altered accordingly. For intermittent operations, a 100% change in heat flux may occur in 10 sec as the clouds sweep across the collector field.



#### Normal Shutdown Mode

An integrated system shutdown shall be coordinated through the plant control subsystem. The system shall be capable of initiating shutdown from any of the above operation modes. The shutdown of the electrical power generation subsystem shall be automatically initiated when the outlet temperature of the thermal storage heat-transfer salt falls 15°C below the specific value. At this point, the electrical generator shall be taken off line and the steam flow to the turbine shall be reduced in a manner consistent with the turbine specifications. Collection of solar energy shall be terminated when insolation falls to such a level that no net energy can be collected (nominally a sun elevation of 10°). The solar radiation incident on the receiver shall be reduced by repositioning each concentrator to its stowed position, and receiver subsystem doors will be closed.

# Emergency Shutdown Mode

The Plant control subsystem shall monitor the status of all subsystems at all times and shall be capable of diagnosing subsystem malfunctions. In the event a malfunction is deemed "serious" (leading to potential equipment damage or safety hazard), an emergency shutdown procedure shall be automatically initiated with manual backup. The procedure shall depend on the nature of the failure but in all cases shall be designed to maximize safety while minimizing equipment damage.

In the event of approaching adverse environmental conditions (wind, sandstorm, rain, hail, etc.), a system shutdown and heliostat reorientation shall be executed after issuance of command by the plant control subsystem. The heliostats shall be off-targeted in a controlled manner to ensure a controlled receiver shutdown. They shall then be directed to a minimum damage orientation in a manner compatible with reflected beam safety considerations. The system shutdown may be limited to the concentrator and receiver subsystems if sufficient energy exists in the thermal storage subsystem to maintain power plant operation.



The time for such shutdown shall be determined to minimize equipment damage and provide maximum safety. The minimum shutdown times shall occur as a result of fluid circulation failure in the receiver. During such an occurrence, the radiation incident on the receiver surface shall be reduced to three percent of its initial value in 30 sec.

### Standby Mode

Following normal shutdown or emergency shutdown modes, the system will be placed in a standby mode. In the standby mode, the plant control subsystem will continue to automatically monitor fluid temperatures and activate heating elements as required to maintain the heat transfer fluid temperature above 171°C (340°F) throughout the receiver, energy transport and energy storage subsystems. No fluid flow or turbine rotation is required in this mode. Concentrators will be in their stowed position and the receiver subsystem doors closed.

### Extended Shutdown Mode

For maintenance, repair, equipment modification, or other reasons, the total system may be infrequently subjected to extended shutdown periods. The heat transfer fluid shall be drained into the storage tanks and normally kept melted there. Trace heating of the receiver and energy transport subsystems are not required.

For startup after extended shutdown, the trace heaters must raise the temperature in the receiver, energy transport, and energy storage subsystems to 171°C (340°F) before flow valves and pumps are activated.

#### A.3.1.5 Reliability/Availability

Design, fabrication, assembly and checkout approaches should be used that maintain a high level of reliability/availability so as to minimize forced or scheduled maintenance. High reliability/availability shall be achieved in the system design by providing adequate operating margins, maximizing the



use of proven standard designs and procedures, maintaining design simplicity, and using conservative design and operational practices. In addition, component redundancy should be considered where justified by cost/performance/availability tradeoffs. The design of the experimental system should be such that the experiment will start up satisfactorily and operate with a high degree of reliability after startup with minimum forced outages attributable to design deficiencies and hardware failures. Further, the experimental system should lead toward small power systems with ultimate reliability/availability approaching that of commercial power plants.

A reliablity/availability goal of 0.95 has been established for a representative power plant at the 1 MWe power level, operating at a capacity factor of 0.4, and assuming simultaneous planned maintenance of subsystems. Availability is defined as the percentage of the total scheduled operating time that the system is able to operate according to specified performance requirements. Availability shall be calculated according to the following formula:

$$A = \frac{Tu - Td}{Tu}$$

where

A = Availability of system for 1 year of operation

Tu = Total scheduled operating time in 1 year (3504 hr for 0.4 capacity factor)

Td = Total downtime during the scheduled operating time for scheduled and unscheduled maintenance

System downtime will occur when either the plant must be shut down during normal operating times for scheduled maintenance (planned outage) or unscheduled maintenance (forced outage) for the repair of malfunctioning components. Component malfunction or failure shall only be considered when total system power output is reduced by two percent or more due to the malfunction. It shall be assumed that unscheduled maintenance of any subsystem or component will be charged as forced outage against operating time regardless of the



time of occurrence during the day. Also, scheduled maintenance on more than one subsystem or component may be performed simultaneously whenever the plant is down.

### A.3.1.6 Maintainability

The collector subsystem shall be designed so that required service can be accomplished by persons having normal skills using a minimum of non-standard tools or special equipment.

The system shall be designed to provide data indicating malfunctions and fault isolation information on critical components. Critical components are those components that, because of failure risk, downtime, or effect on overall plant performance, materially affect the system availability or the system safety.

Items which do not have a redundant mode of operation shall have the maximum capability for on-line repair or replacement. These items might include, for example, sensors and actuators. The system shall be designed so that potential maintenance points can be easily reached, the reflector can be readily cleaned, replaceable components such as electronic modules and sensors can be readily replaced, and elements subject to wear or damage can be easily serviced or replaced.

To achieve the required system maintainability, the system shall be designed such that:

- A. Items that are critical to availability (because of high failure risk, high downtime, or major effect on system performance) shall be provided with automatic failure detection.
- B. The equipment shall be designed to contain the minimum number of test points required to ascertain satisfactory performance of all primary and redundant circuits.
- C. Test points and instrumentation are accessible for inspection and calibration and repairs can be accomplished by module replacement.



- D. Potential maintenance points can be reasonably reached and replaceable components (electronic units, sensors, motors, drives, etc.) can be readily replaced.
- E. Elements subject to wear or damage can be easily inspected, serviced or replaced.
- F. Equipment expected to require servicing or maintenance shall be designed to be accessible without the removal of other equipment, wire bundles, and fluid lines.
- G. Components shall be designed so that they cannot be installed improperly.
- H. Automatic valves shall be designed to have manual bypass or shutoff capabilities.
- I. Reservoirs and storage vessels shall be provided with shutoff valves for maintenance.
- J. The plant can be serviced by personnel of normal skills requiring a minimum of specialized equipment or tools.

### A.3.1.7 Transportability

#### Sizing and Weight Limitations

System elements shall be designed for transportability within applicable Federal and state regulations by highway and railroad carriers using standard transport vehicles and materials handling equipment. Whenever feasible, components shall be segmented and packaged to sizes that are transportable under normal commercial transportation limitations (see A below). Subsystem components that exceed normal transportation limits (see B below) shall be transportable with the use of special routes, clearances, and permits.

A. Transportability limits for normal conditions-permits not required (Standard limitations in English units)

	<u>Truck</u>	<u>Rail</u>
Height	13 ft 6 in above road	16 ft 0 in
Width	8 ft 0 in	10 ft 6 in
Length	55 ft O in - Eastern States	60 ft 6 in
	60 ft 0 in - Western States	
Gross Weight	73,280 lb, 18,000 lb/axle	200,000 lb



B. Transportability limits for special conditions-permits required (Standard limitations in English units)

	<u>Truck</u>	<u>Rail</u>
Height	14 ft 6 in above road	16 ft 0 in above rail
Width	12 ft 0 in	12 ft 0 in
Length	70 ft 0 in	80 ft 6 in
Gross Weight	100,000 lb, 18,000 lb/axle	400,000 lb

# Shock and Vibration Limitations

The design requirements for component packaging and tiedown techniques shall be compatible with the following limit load factors.

٧	i	b	r	a	t	i	0	n	

Transportation Mode	Amplitude (G <sub>op</sub> )		Frequency Range (Hz)
Highway	±0.6		1 - 85
	±0.9		85 - 300
Air	±0.05 in D	.A.	3 - 38
	±2.0		38 - 1,000
Rail	±1.0		1 - 100
	1.6		100 - 1,000
Shock Load Factors	Ac	celeratio	n (g)
Transportation Mode	<u>Longitudinal</u>	Lateral	<u>Vertical</u>
Air	±3.0	±2.5	±2.0
Highway	±3.5	±2.0	±3.0
Rail			
Rolling Humping (Hydro cushion car	±3.0 ±3.0	±0.75 ±2.0	±3.0 ±3.0

All critical components shall be designed or packaged such that the conditions described above do not induce a dynamic environmental condition which exceeds the structural capability of the component. These conditions reflect careful handling and firmly constrained (tied down) transporting via common carrier.

All components shall be designed to withstand handling/hoisting inertial loads up to 2 g's considering the number, location and type of hoisting points.

Handling shock will result from normal handling drops of large packaged equipment. Corresponding acceleration peak may be of the order of 7 g's vertical and 4 g's horizontal with a sinusoidal profile and a duration of 10 to 50 msec.

Smaller components shall be properly packaged to prevent structural damage during normal handling and inadvertent drops to a maximum specified height. The handling shocks for these components are a function of the weight and dimensions of the packaged item. Structural analyses shall be performed for critical items to establish the structural integrity of the packaged component for the shock levels experienced in the shipping package. The drop height noted below shall be used as design guidelines for the packaged item.

Gross Weight Not Exceeding (1b)	Dimensions of Any Edge, Height, Diameter (in)	Drop on Corners, Edges, or Flat Faces (in)
50	36	22
100	48	16
150	60	14
No Limit	No Limit	12

### A.3.1.8 Producibility

#### Materials, Processes, and Parts

To the maximum extent possible, standard materials and processes shall be employed. Highly stressed components and unusual materials shall be avoided. As far as practical, off-the-shelf components used in industry shall be employed. Materials and components, susceptible to environmental deterioration shall be protected with a suitable coating or protective layer.



### Workmanship

The level of workmanship shall conform to practices defined in the codes, standards, and specifications applicable to the selected site and the using utility. Where specific skill levels or certifications are required, current certification status shall be maintained with evidences available for examination. Where skill levels or details of workmanship are not specified, the work shall be accomplished in accordance with the level of quality currently in use in the construction, fabrication, and assembly of commercial power plants. All work shall be finished in such a manner that it presents no unintended hazard to operating and maintenance personnel, is neat and clean, and presents a generally uniform appearance.

### Nameplate and Product Marking

All deliverable end items shall be labeled with a permanent nameplate listing, as a minimum, manufacturing, part number, change letter, serial number, and date of manufacture. All access doors to maintainable items shall be labeled to show equipment installed in that area, and any safety precautions or special considerations to be observed during servicing.

#### Hardware Acceptance

A method will be provided whereby conformance of hardware to the design and to the applicable detail specifications will be verified as system elements are manufactured and as the system is integrated. For purposes of plant acceptance, this verification of conformance includes proof-by-assembly, the examination of inspection and test records, and subsystem and system demonstration.

#### Formal Qualifications

Formal design qualifications shall require satisfactory completion of all required tests, include those specified for subsystems, and the completion of all other required verifications and the integrated system demonstration tests.



### A.3.1.9 Human Engineering and Operation

### Human Engineering

The system shall be designed to facilitate manual operation, adjustment, and maintenance as needed, and to provide the optimum allocations of functions for personnel or automatic control. Particular design attention shall be given in the receiver subsystem to location of equipment in relation to elevators, walkways, and ladders, provision of adequate lighting for night maintenance, and placarding of hazardous work areas. MIL-STD-1472, Human Engineering Design Criteria, shall be used as a guide in designing control stations and equipment, with considerations given to personnel operations and interfaces - e.g., displays, controls, labels and placards, equipment handling, and providing a desirable working environment.

#### A.3.1.10 Logistics

### Operating Personnel

The Small Power System Experiment is to be installed, checked out, and tested by contractor personnel. Operation and maintenance personnel requirements shall be satisfied by contractor personnel and from the established servicing or utility labor pools.

#### Training

System uniqueness and utility interfaces dictate a need for training, but do not establish a need for new skills or trades. The types of training and number of personnel requiring training shall be determined for each major subsystem.

#### Documentation

Documentation of subsystem design, performance, operating, test characteristics, instructions, construction drawings, procedures and parts lists and



related information shall be prepared in accordance with the requirements of subsystem requirements specifications.

# Spares and Interchangeability

Consideration for spares and interchangeability shall be given for common items such as heliostat reflective panels, drive instrumentation, wiring connectors, attachment bolts, support brackets, etc. Components with common functions shall be produced with standard tolerances and connector locations to permit interchange for servicing. Quantities of spares and repair parts to be available for the experimental plant shall be specified for each subsystem.

### Maintenance Equipment and Facilities

Maintenance equipment and facilities at the site shall be limited to a small servicing room in the main site facility building and a service truck with standard hand tools, and standard electronics checkout/calibration equipment. Specific requirements for maintenance and repair, such as hoists, slings, working platforms, etc., shall be provided.

Servicing at the site will be preferred for all permanently installed equipment. Minor plant equipment (such as instrumentation, valves, heaters, fluid lines, electrical lines, switches, etc.) will be serviced at the site using standard equipment and parts.

Maintenance activities shall be categorized as follows:

Level 1, On-line maintenance

Level 2, Off-line on-site maintenance

Level 3, Off-line off-site maintenance

Maintenance actions for each subsystem shall be identified in the Subsystem Requirements specification.



### A.3.1.11 Safety

The Small Power System Experiment shall be designed to minimize potential hazards to operating personnel, equipment, and the general public. Safety considerations shall include equipment design and facilities, safety features and warning devices, and personnel safety operating procedures.

### Equipment Design and Materials

Sufficient analyses shall be conducted to assure that equipment design and the selection of materials consider the following:

- A. Incorporation of "fail-safe" principles where a failure would disable the system in order to prevent either injury to personnel or damage to equipment.
- B. Grounding and insulation of electrical supplies and components.
- C. Insulating parts or components with elevated temperatures or shock potential to prevent contact with or exposure to personnel.
- D. Providing lightning protection, as necessary, in accordance with standard safety specifications.
- E. Controlling and minimizing the potential damage to personnel and equipment from hazards which cannot be avoided or eliminated.

#### Safety Features and Warning Devices

Sufficient analyses shall be conducted to assure that adequate safeguards and warning devices are incorporated, including the following:

- A. Providing appropriate circuit and line safeguard devices (such as current limiters, voltage regulators, relief valves and interlocks) for power source, personnel, and equipment protection.
- B. Providing emergency shutoff valves and switches, fire extinguishers and fire escape paths for areas that have hazardous material or ignition sources.
- C. Shielding moving elements to avoid entanglements and providing safety override controls and/or interlocks for servicing.



D. Isolating hazardous substances, components, and operations from other activities, areas, personnel, and incompatible materials.

### Operational Safety Procedures

Sufficient analyses shall be conducted to assure that adequate safety procedures will be employed for all operating personnel and the general public, including the following:

- A. Establishing criteria and recommendations for restricted operations or personnel access.
- B. Locating equipment components so that access to them by personnel during operation, maintenance, repair, or adjustment shall not require exposure to hazards such as burns, electrical shock, cutting edges, sharp points, insecure footing, or toxic atmospheres.
- C. Avoiding undue exposure of personnel to physiological and psychological stresses which might cause errors leading to mishaps.
- D. Providing suitable warning and caution notes in operation, assembly, maintenance, and repair instructions; and distinctive markings on hazardous components, equipment, or facilities for personnel protection.

### A.3.1.12 Installation and Interfaces

#### Site Location

For preliminary design purposes, the installation site for the Small Power System Experiment shall be assumed to be located near Barstow, California.

### Field Installation

Installation of the subsystems at the field site shall be accomplished using standard transportation and handling equipment (including the possible use of helicopters for receiver assembly installation). Component breakdown shall be such that the equipment and labor for field installation (structural, fluid, electrical, instrumentation and control interfaces) are minimal.



The system shall be installed so as to minimize susceptibility to electromagnetic interference and to minimize the generation of conducted or radiated interference. Also, plant operation shall not be adversely affected by external or internal power line transients caused by normal switching or fault clearing.

### Utility Interfaces

Engineering Experiment No. 1 shall be designed to provide remote load centers, small communities, rural areas and industrial users with a supplementary energy source. The plant shall therefore be physically and functionally compatible with standard electric power transmission networks. Electric power shall be generated by the plant at a power level of 1.0 MW, a voltage of 13.8 kV and a frequency of 60 Hz. Appropriate electrical conditioning and interface equipment (transformers, capacitors, circuit breakers, cables, connectors and controls) shall be included to provide synchronized power to the utility network at a voltage of 69 KV. Also appropriate electrical equipment shall be included to provide auxiliary power at 440 volts for plant subsystem operations.

Operating interfaces with the utility grid shall also include considerations of power profiles, dynamic interactions, and emergency operations. Nonoperating interfaces shall include considerations of startup and shutdown sequencing, outage due to planned or forced maintenance and extended shutdown periods.

Stand-alone power plant capabilities shall also be evaluated in which startup, shutdown, and holding power requirements are to be provided by auxiliary power generating equipment. The additional equipment and plant interfaces for this capability are to be identified separately from the basic small solar power system experiment.

### Community Interfaces

In the installation and operation of the power plant, considerations shall be given to the environmental, hazard and aesthetic interfaces with local



communities. Local environmental concerns shall include noise, air pollution, water pollution, flood control, erosion and dust control, and plant and animal ecology. Local hazard concerns shall include explosion, fire, toxicity, radiation, leaks and glare. Aesthetic concerns shall include general plant appearance, landscaping, access routes and traffic impact.

# A.3.2 Collector Subsystem Requirements - Concentrator Assembly

### A.3.2.1 Design Requirements

### Reflective Unit

The reflective unit shall be divided into two identical or mirror image reflector panels. Each panel shall be transportable by common carrier and installed with a minimum of field labor and equipment. The heliostats should reflect the sunlight with a combined beam and tracking error of less than 3 mr standard deviation, and concentrate the maximum cost-effective fraction of the sun's light on the receiver in the prescribed distribution. Each reflector panel is comprised of six mirror modules and a support structure.

#### Mirror Module

The mirror modules shall consists of second surface glass, slightly curved to enhance focusing. The mirrors shall be constructed such that their clean structural reflectivity shall be equal or greater than 0.88. The mirror modules shall be prealigned on panel supporting structure. Each mirror module shall have individual support attachments that can be easily adjusted in the field for alignment, as required.

# Support Structure

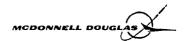
The panel support structure shall maintain the alignment of the mirror modules, provide an adjustable attachment for each mirror module, and provide a rigid attachment to the drive unit. The support structure shall be made of roll formed channel or tubular steel shapes.

### Pedestal/Foundation

A central steel pedestal concept shall be employed. The pedestal shall be rigidly attached to the foundation by bolted flanges or slip joints. For the 3.5-year program, the DOE 10 MWe Pilot Plant concept shall be employed. For this case, the foundation shall be a reinforced precast concrete foundation with bolted flames for pedestal attachment. Each foundation unit shall be precast offsite and shipped to the site for installation. For the 4.5- and 6.5-year programs, the Prototype Heliostat concept shall be employed in which the foundation is a drilled pier incorporating a tapered steel shell at the protruding end of the pier over which the pedestal is slipped. The final design of the foundation and installation procedures shall require a comprehensive knowledge of the soil-bearing capacity at the particular site. Foundation design shall include consideration of soil stratigraphy, preservation of vegetation, and geological phenomena. The pedestal and foundation shall limit the reflective surface deflection to 1.7 mrad (one standard deviation) under normal and operational environmental conditions. A maximum allowable foundation settlement or plastic displacement of 0.05 mrad ( $1\sigma$ ) and elastic displacement of 0.5 mrad ( $l\sigma$ ) must be included in the allowable structural support deflection limit for any environmental condition excluding earthquakes. Realignment after earthquakes is acceptable.

### Drive Unit

Each heliostat shall incorporate an azimuth and elevation drive mechanism to produce movement of the reflector surface about its axes of rotation. The drive unit, which is mounted on the top of the pedestal, is composed of a motor, drive transmission, position feedback transducers, reflector support bearings and a structural housing. The drive unit must be capable of positioning the heliostat reflector surfaces such that at any time the maximum mirror normal pointing error for each gimbal axis shall be 0.75 mrad (one standard deviation) whenever the sun is at least 0.26 rad above the horizon. Elevation and azimuth drives shall not drift from last commanded position due to environmental factors. The drive unit must also be capable of positioning the heliostat from any operational orientation to inverted stowage, cleaning,



maintenance of any other desired positions. Provisions shall also be provided that enable the heliostat to be stowed manually without the use of the drive motors. Drive systems shall be environmentally sealed and corrosion protection shall be provided for all exposed parts.

### Heliostat Controller

Heliostat controls and associated electronics and instrumentation, which are mounted on the drive unit, are covered in Section A.3.8 and 4.2.

### Power Distribution

Electrical power shall be supplied to the drive units of each heliostat by means of one or more primary power cables running from the plant control building into the field. Branch circuits from the primary power cables shall be employed to provide power to individual heliostats. In this manner, uninterruptable plant power is to be supplied to the heliostat field controller(s) and heliostats. The primary cables and branch circuits shall be underground. The power lines shall be sized to provide sufficient power for the simultaneous rotation of all heliostats for emergency stowage conditions. Concentrator equipment shall not be adversely affected by the following electrical power transients:

Normal Operating - voltage ±10% - frequency ±0.1%

Equipment startup

or shutdown - voltage -25%, +10% with recovery within 5 cycles at 60 Hz

Emergency - momentary total loss of power Condition



## A.3.2.2 Environmental Requirements

The heliostats shall be capable of operating in and surviving appropriate combinations of environmental conditions that include temperature extremes, winds and gusts, rain, hail, snow and ice, seismic loads, and lightning, as defined in the following subsections.

### Temperature

The heliostats shall be able to survive, without damage, and be able to operate in an ambient air temperature range from  $-30^{\circ}$ C ( $-22^{\circ}$ F) to  $60^{\circ}$ C ( $140^{\circ}$ F). The heliostats shall be able to operate and meet performance specifications in an ambient air temperature range from  $0^{\circ}$ C ( $32^{\circ}$ F) to  $+40^{\circ}$ C ( $104^{\circ}$ F).

### Winds and Gusts

- Survival conditions The plant (with the heliostats stowed) shall survive, without damage, winds and gusts with a maximum speed of 40.2 m/s (90 mph) from any direction. This condition is based on a lout of 25 year mean recurrence probability. It includes a 1.2 gust factor. Heliostat structural design stresses at 90 mph winds have a 1.5 factor of safety per AISC specifications (American Institute of Steel Construction). Gust induced angles of attack up to 10 degrees shall be considered (applicable to the vertical velocity component). The plant (with the heliostats in the operational position) shall survive, without catastrophic failure, winds and gusts up to 22 m/s (50 mph) in the most adverse orientation. This condition could result from unusually rapid wind rise rates, such as severe thunderstorm gust fronts.
- Operating conditions The system must be capable of operating in a 13 m/s (29 mph) wind. Maximum operational wind speeds shall be selected based on tradeoffs between plant and energy costs. A maximum operational windspeed of 16.1 m/s (36 mph) has been established for preliminary design. Heliostat stowage will be initiated at this speed. A maximum wind rise rate of 0.01 m/s<sup>2</sup> (1.3 mph/min) shall be used in calculating wind loads during stowage. Wind velocity

profile varies exponentially with height to the 0.15 power, where the reference height is taken as 10 m (30 ft).

$$v_z = v_{10m} \left(\frac{z}{10m}\right)^{0.15}$$

where:

 $V_{10m}$  = reference wind velocity at height of 10 m

0.15 = power law exponent for flat open country

Z = height in meters

 $V_{z}$  = mean wind velocity at height Z

The wind speed frequency of occurrence at a reference height of 10 m (30 ft) is:

Speed (m/s)	Frequency (Percent)
0-2	29
2-4	21
4-6	19
6-8	14
8-10	8
10-12	5
12-14	3
>14	<1

#### Dust and Sandstorms

The plant shall survive, without damage, blowing dust comparable to the test conditions described by MIL-STD-810B, Method 510. Dust devils with wind speeds up to 17 m/s (40 mph) shall be survived without damage to the plant in the operational mode.



### Rain, Snow, Ice and Hail

The plant (with the heliostats in the stowed position) shall survive, without damage, the following environmental conditions:

- Rain: Average annual amount of 750 mm (30 in) at a maximum 24 hour rainfall rate of 75 mm (3 in)
- Snow: 250 Pascals (5 lb/ft<sup>2</sup>) at a deposition rate of 0.3 m (1 ft) in 24 hr
- Ice: Freezing rain and ice deposits in a layer of 50 mm (2 in) thick
- Hail:

	Any Orientation	Stowed	
Diameter	20 mm (3/4 in)	25 mm (1 in)	
Specific Gravity	0.9	0.9	
Terminal Velocity	20 m/s (65 fps)	23 m/s (75 fps)	

### Seismic

The heliostats must survive, without structural damage or yielding, an earth-quake that would produce an acceleration on the order of 0.20 g to 0.25 g horizontal and vertical ground accelerations and shaking intensity of about VII to VIII on the Modified Mercalli Scale. The spectral presented in U.S. Atomic Energy Commission (Revision 1, dated December 1973) Regulator Guide 1.60 should be used as a guide. In addition, the heliostats must satisfy the requirements specified for Seismic Zone 3 in the Uniform Building Code. Realignment of the heliostats after an earthquake is allowed.

# Lightning

The plant shall be provided with lightning protection. Total destruction of a single heliostat and its controller subjected to a direct lightning strike is acceptable. Damage to a heliostat adjacent to a direct lightning strike should be minimized within appropriate cost-risk limits. The plant controller and local controllers of collectors adjacent to a direct lightning strike must be protected to minimize loss of collection system control.



### A.3.2.3 Interface Requirements

# Physical Interfaces

The physical arrangement and boundaries of the array of heliostats shall be optimized to produce the required heat flux on the receiver in the most cost-effective manner. The arrangement of heliostats shall reflect balanced consideration of heliostat geometric parameters, blocking, shading and servicing. The concentrator subsystem shall concentrate at least 95% of the redirected energy onto the receiver absorber.

### Structural Interfaces

Heliostat foundations shall be consistent with the site-peculiar stratigraphy and surface soil conditions. Structural provisions shall be made at the top of the drive unit to mount the heliostat controller.

### Electrical Power Interfaces

Electrical power junction boxes and switches shall be provided at the Plant Control building for interfaces with the field power cables.

#### Instrumentation and Control

Interconnections between the drive unit and the heliostat controller and instrumentation shall be provided.

#### A.3.2.4 Fabrication and Installation Requirements

#### Manufacturing and Assembly

To the maximum extent possible, standard materials and processes and off-the-shelf components shall be used. Manufacturing shall be based on high production assembly-line machinery and processes compatible with the 10 MWe Barstow Pilot Plant production program. All elements of the concentrator subsystem shall be



fabricated and checked at the off-site fabrication facility. The heliostat reflective units are divided into two factory preassembled, transportable panels which are identical and interchangeable. However, mirror module panel curvature and nominal cant angles shall be preset in the factory. A single curvature is employed and up to five cant angles are allowed for specific zones in the field. The drive unit is delivered to the field with the heliostat electronics installed. Panel cant angles may be adjusted in the field, using standard spacer kits. Wherever possible, commercial specifications shall be employed. All non-commercially available parts shall be defined and documented in delivery documents. Commercial items shall not be proprietary.

### Transportation and Handling

Heliostat elements must be transportable by truck or rail within applicable Federal and state regulations. Handling rings must be provided for all large and heavy elements.

### Field Installation

For the 3.5-year program in which the Barstow 10 MWe Pilot Plant heliostat concept is used, a drill rig shall be used to dig a round excavation, and a special straddle carrier and setting/bedding machine shall be used to set the precast concrete foundation in place. For the 4.5- and 6.5-year programs, in which the Second Generation Heliostat is used, a drill rig and crane shall be used to set the steel capped rebar cage in place. Concrete shall be poured to fill the excavation and the tapered steel caps. The drive unif, together with electronics, shall then be assembled to the pedestal in the field. Each reflector panel (two per heliostat) will then be attached and adjusted. Electrical power and control cables for each heliostat shall be installed at the field site.

# Checkout and Adjustment

The two reflector panels of each heliostat shall be attached to the drive unit and adjusted in the field by installation crews with normal skills and minimal



training. The cant angles of each mirror module on the panel shall also be adjustable to allow for fault correction and fine tuning, as required. In addition, special provisions shall be provided to periodically calibrate the aiming and control accuracy of each heliostat while the plant is in a normal operating mode.

### A.3.2.5 Maintenance and Repair Requirements

### Reliability/Availability

Design, fabrication, assembly and checkout approaches should be used that maintain a high level of heliostat reliability/availability so as to minimize forced or scheduled maintenance. High reliability shall be achieved by providing adequate operating margins, maximizing the use of proven standard parts and using conservative design and operational practices. Single-point failures that disable the automatic mode of system operation shall be eliminated where practical. Malfunctions of critical components shall be detected and signalled through the plant control subsystem. Major failure modes that should be minimized include power failures, drive unit malfunction, and panel/mirror damage or warpage due to environmental conditions. Items which do not have a redundant mode of operation shall have the maximum capability for on-line repair or replacement. Design and material selection shall be based on a 30-year plant life.

#### Maintenance Procedures

The heliostats shall be designed so that they require a minimum of routine field maintenance with the exception of periodic washing. Preventive maintenance, including visual inspection, cleaning, painting, continuity and functional checks, adjustment, and mirror repair, shall be employed. Subassemblies shall be designed to facilitate manual operation, adjustment and maintenance as needed by persons having normal skills using a minimum of nonstandard tools or special equipment.



### Spares and Interchangeability

Only a minimal inventory of spares shall be considered at the site, which includes individual mirrors elements, attachment bolts, nuts and shims, electrical wiring and connectors. Major repair of the pedestal, drive unit or main structural elements shall be conducted at the assembly plant. Items with a common function shall have a common part number and be interchangeable. Components with similar appearance, but different functions shall incorporate protectors against inadvertent erroneous installation. All heliostats (pedestal, drive unit, structural assembly and panels) shall be interchangeable regardless of their position in the heliostat array; however, cant angle adjustments of each panel are permissible depending upon specific heliostat locations. All mirror elements on each panel shall also be interchangeable, provided proper cant angle adjustments are made.

### Maintenance Equipment

Mirror washing equipment shall be required at the site. Provisions (ladders, portable working platforms) must also be available for the inspection and servicing of concentrator subassemblies, particularly for mirror adjustment or replacement. The collector subsystem shall provide electrical outlets that will ensure rapid maintenance with standard hand tools and adequate light for night work.

#### A.3.2.6 Safety Requirements

# Equipment Design and Materials

Commercial design and construction standards shall be employed to minimize safety hazards to operating and service personnel, the public and equipment. No combustible materials shall be used in the concentrator subsystem. The heliostat field shall not be vulnerable to extensive fire damage augmented by winds, component explosions or any other means. Electrical components shall be insulated and grounded. Moving elements shall be sufficiently elevated or shielded to avoid personnel entanglements. Safety override controls/interlocks shall be provided for servicing. All pertinent OSHA rules and regulations shall be observed.



### Safety Features and Warning Devices

Working platforms and ladders shall have suitable tiedowns or structural supports for safe manned servicing operations. Physical security provision shall be included for the collector field to protect against damage by animals, sabotage or vandalism.

### Operational Safety Procedures

Override and/or disable control features shall be employed when servicing individual heliostats while the plant is in the normal operating mode. Beam control strategy and equipment shall protect personnel and property within and outside the plant facility including air space.

# A.3.3 Collector Subsystem Requirements - Receiver Assembly

# A.3.3.1 Design Requirements

The receiver subsystem consists of an absorber unit, structural assembly (including housing and doors), controls and instrumentation, insulation, and heaters. The function of the receiver subsystem is to absorb the solar radiation reflected from the mirrors of the collector subsystem and transfer that energy into the heat transfer fluid circulated through the receiver unit by the energy transport subsystem. Receivers for the 3.5, 4.5 and 6.5 year programs will utilize Hitec/HTS fluid in a cavity or partial-cavity arrangement. Receivers will be configured for best thermal efficiency, consistent with acceptable heat transfer/fluid flow characteristics and minimum cost. Overall design requirements are listed in Table A-3.

The major components and interfaces of the receiver are defined below.

### Absorber Unit

The absorber unit is an assembly of small diameter pipe, configured in a conical spiral to absorb the energy from the heliostat field without exceeding fluid temperature limits. The piping is connected to form one or more



Table A-3. Receiver Design Requirements

	3-1/2 Yr	4-1/2 Yr	6-1/2 Yr
	*	*	**
Peak Power, MWt	7.08	6.05	4.87
Fluid	Hitec	Hitec	HTS
Flow Rate, kg/hr	84,000	62,800	44,900
(lg/hr)	(185,100)	(138,400)	(99,000)
Inlet Temperature, °C (°F)	260	288	288
	(500)	(550)	(550)
Outlet Temperature, °C (°F)	454	510	538
	(850)	(950)	(1000)
Maximum Film, °C (°F)	496	538	566
	(925)	(1000)	(1050)
Aperture Diameter, m (ft)	4.50	4.28	4.00
	(14.76)	(14.05)	(13.12)

<sup>\*</sup>Axial turbine

parallel flow paths for the receiver fluid. No gasketed joints are permitted in the fluid flow paths of the absorber. Pressure drop through the receiver should not exceed  $68.95 \text{ N/cm}^2$  ( $100 \text{ lb/in}^2$ ). Heat is transferred to the fluid by forced convection. The absorber must be removable, as a single unit, from the receiver assembly.

Absorber support connections will be pinned or bolted to facilitate removal. Fluid inlet/outlet disconnection may require the cutting of welds.

# Structural Frame, Housing and Doors

The structural frame is a weldment or a built-up assembly of rolled structural steel shapes which supports the absorber unit and the other elements of the receiver, and provides for attachment to the tower. This structural assembly will be enclosed within a weatherproof housing, constructed of corrugated metal or asbestos cement sides and roof and a steel floor, bolted to the structural assembly. The housing must provide for access for inspection and maintenance of the receiver elements. Environmental conditions are specified in Section A.3.1.3.



<sup>\*\*</sup>Radial turbine

An insulated door(s) will be provided, to prevent excessive heat loss from the aperture during nighttime or normal shutdown. An overall heat transfer coefficient less than 8.51 x  $10^{-4}$  kW/m $^2$  °C (0.15 Btu/hr ft $^2$ °F) is required. Door operating mechanisms will be electric motor driven. Maximum time to open or close shall be 60 sec.

# Controls and Instrumentation

Temperature, pressure, and flow sensors will be provided for the fluid circuits within the receiver (see Section A.3.8). Appropriate valving or orificing will be installed to: (1) proportion the fluid flow through the parallel circuits of the absorber unit, if required, (2) provide necessary pressure control or venting of gases.

### <u>Insulation</u>

Thermal insulation is required for the back side of the absorber assembly and for all fluid piping, vent piping and high-temperature components. Design values for the maximum heat transfer coefficient for the insulation assembly are:

Component	Transfer Coefficient, Max.			
Absorber	$5.67 \times 10^{-4} \text{ kW/m}^2 \text{ °C } (0.1 \text{ Btu/hr } \text{ft}^2 \text{ °F})$			
Connecting Piping	$5.67 \times 10^{-4} \text{ kW/m}^2 \text{ °C } (0.1 \text{ Btu/hr ft}^2 \text{ °F})$			
Valves, Instrumentation	$1.70 \times 10^{-3} \text{ kW/m}^2 \text{ °C } (0.3 \text{ Btu/hr ft}^2 \text{ °F})$			

#### Heaters

An electrical trace heating system is required for the absorber and all fluid piping and valves. The system must be capable of heating the absorber, piping, valves, etc., to a temperature of at least 171°C (350°F) for Hitec systems and 260°C (500°F) for the binary HTS salt used in the 6.5-year program from a 20°C ambient in no more than 12 hr.



### Scatter Shield

A thermal shield is required at the edge of the aperture to prevent damage to the tower and receiver structure from normal spillage radiation and heliostat aiming transients. Energy incident on the shield will be reflected or reradiated. Design heat flux is 0.02 MW/m ( $6.300 \text{ Btu/hr ft}^2$ ) at the edge of the aperture, decreasing to zero at 0.30 m (12 in) from the edge. Design maximum temperature at the back surface (facing the tower) is  $125^{\circ}\text{C}$  ( $257^{\circ}\text{F}$ ).

### Structural Interfaces

The receiver/tower interface plane is located at an elevation of 39.09 m above plant grade and the center of the aperture is at elevation 41.89 m. Provisions will be included in the receiver structural assembly for bolting the total receiver unit to the top of the tower.

### Fluid Interfaces

Fluid connections between the receiver and the energy transport subsystems (riser and downcomer piping) are located inside the receiver housing, near the receiver/tower interface plane.

#### Electrical Power

The electrical power service box will be located inside the receiver housing, near the receiver/tower interface plane. It will supply power for the door mechanism, heaters and lighting.

#### Instrumentation and Control

Service box and terminal strips will be located inside the receiver housing, near the receiver/tower interface plane, for the purpose of transmitting instrument readings (temperature, pressure, flow rates, valve and door position) and control (doors, heaters, vent).



### A.3.3.2 Operational Requirements

### Startup Mode

Startup will begin with a signal from the operator which initiates a series of receiver prestart checks (valve positions, temperatures, pressures). Any out-of-normal receiver startup operating conditions will be monitored at the plant control station. Under normal conditions, the receiver will have been in an overnight standby mode and fluid temperatures will have been maintained at 171°C (350°F) by residual heat in the system or by the trace heaters. At startup command, flow valves will open, pumps will start, and fluid flow will begin. Once steady state flow has been established, the receiver doors will be opened by the operator and solar heating will commence. For cold starts after an extended shutdown period, fluid flow will not be initiated until all heat transfer fluid, fluid lines and valves have been brought up to 171°C (350°F) for Hitec systems or 260°C (500°F) for HTS systems.

### Normal Operating Mode

Under normal operating conditions, the fluid flow rate will be varied in proportion to the solar radiation so that receiver outlet temperature will be maintained at rated values as specified on Table A-3.

#### Intermittent Mode

For intermittent cloud passage, the receiver controller will reduce the amount of fluid flowing through the receiver to maintain rated receiver outlet temperature as long as possible. When reduced insolation no longer permits rated output conditions, the total receiver flow will be reduced to a minimum operating value of 10 percent of nominal and directed back to the cold storage tank. For intermittent operations, the receiver must withstand a 100% change in heat flux in 10 sec as clouds sweep across the collector field.



solidify. No provisions for drainage of this residual fluid is required. In this condition, maintenance or repair can be conducted safely on the absorber unit or other receiver elements. For startup with the receiver tubes in this condition, trace heaters must raise the temperature in the receiver unit to at least 171°C (350°F) before flow valves are opened.

### A.3.3.3 Fabrication and Installation Requirements

# Manufacturing and Assembly

Manufacturing planning for the experimental plant will be based upon small production runs (1 to 10 units), standard, proven manufacturing processes, and the use of general-purpose machine tools. Assembly fixtures will be minimal. The total receiver subsystem, including instrumentation, will be assembled at the factory and checked before shipping to the site. Minor disassembly for shipping is permissible.

### Transportation and Handling

The total receiver and/or components of the receiver must be transportable by truck and rail. Lifting points for clevis/cable rigging attachments will be provided on the total receiver subsystem or those components which must be assembled on the tower.

#### Field Installation

Component breakdown will be such that the equipment and labor required for field installation (structural, fluid, electrical, instrumentation and control interfaces) are minimal. Nonstructural welding (i.e., fluid piping) may be required at the tower-top location.

# Checkout and Adjustment

The absorber unit assembly will be pressure tested and leak checked at the factory before shipment. Instrumentation will be fit- and flow-checked before installation. The complete receiver (structural assembly, absorber unit,



insulation, heaters, instrumentation and controls) will be assembled at the factory and flow checked.

### A.3.3.4 Maintenance and Repair Requirements

### Reliability/Availability

Design, fabrication, assembly and factory checkout approaches should be used that maintain a high level of receiver reliability/availability so as to minimize forced or scheduled maintenance. Major receiver failure modes that should be minimized are fluid line leaks, clogged tubing, and instrumentation malfunctions.

### Maintenance Procedures

All major receiver elements, including the absorber unit, must be accessible for maintenance and repair without removing the entire receiver unit from the top of the tower. Capabilities must be provided that would enable the absorber unit to be removed from the structural assembly/housing and lowered to the ground for maintenance or replacement. The receiver housing should be designed for periodic visual inspection of the absorber unit, structural assembly, instrumentation, valves and insulation. Instrumentation, vent valves and heating elements must be periodically checked by calibration techniques. Preventive maintenance of the receiver subsystem while on the tower includes visual inspection, cleaning, painting, continuity checks, functional checks, and periodic flushing and parts replacement.

# Spares and Interchangeability

Since the total receiver subsystem for the experiment is to be assembled and checked out at the factory before shipping, there are no requirements for a full receiver spare at the site. Spare parts will include instrumentation, attachment devices and expendable items (gaskets, etc).



#### Normal Shutdown Mode

When the insolation approaches the point where the specified outlet temperatures cannot be maintained at a minimum flow rate of 10% of nominal, a controlled shutdown process will begin. In a coordinated manner, the fluid flow valves will be closed, the heliostats slewed away from the receiver, the receiver doors closed, and trace heating initiated (if required).

### Emergency Shutdown Mode

In the event of abnormal operation of the receiver, as indicated by low or high flowrates, pressures or temperatures, the receiver instrumentation systems must detect the abnormality and alert the plant operator. If operator remedial actions cannot resolve the problem before trip limits are exceeded, the control system will automatically begin an emergency shutdown procedure. Emergency slewing of the heliostats off the receiver to remove the heat source will begin, and fluid flow rates will be reduced. If necessary, excessive receiver tube pressures will be vented. When the heat flux from the heliostat field has been significantly reduced, the receiver doors will be closed, and the fluid flow stopped. System checkout and inspection procedures will then be initiated to determine the cause of the abnormal operation. Typical conditions which could result in emergency shutdowns are: a loss of receiver fluid at the inlet, a large leak in the receiver, an obstruction in the tubing, or a sudden and significant change in the radiation from the heliostat field.

#### Extended Shutdown Mode

Extended shutdown with fluid/component temperatures reduced to ambient conditions, may be required for prolonged adverse weather conditions, and will be required for maintenance or repair of certain receiver elements or other subsystems. For extended shutdown without trace heating, the heat transfer fluid will solidify. The shutdown mode for these conditions is the same as for normal shutdown, except that trace heaters will not be activated. Hot fluid in the receiver will be drained into the thermal storage tank by GN<sub>2</sub> purge, however, some fluid will remain in the coils of the absorver unit which will

### Maintenance Equipment

No major maintenance equipment is required at the site for the receiver subsystem. Provisions must be available for raising (by crane or helicopter) and lowering the absorber unit or other components. Calibration equipment must be available to periodically check out the operations of instruments, vent valves and heating elements. Working platforms on the tower with protective rails will be required for receiver inspection, maintenance and repair.

Maintenance equipment for the receiver subsystem at the site must include:

- A. Absorber unit handling sling
- B. Standard hand tools, power hacksaw or pipe cutter, welder, spray painting equipment
- C. Standard electronics checkout/calibration equipment (pressure, temperature and flow instruments, vent valves).

#### A.3.3.5 Safety Requirements

### Equipment Design and Materials

Design stresses for the absorber tube assembly shall not exceed the maximum allowed by the ASME Boiler Code for the materials used.

No combustible materials shall be used in the receiver assembly.

# Safety Features and Warning Devices

Pressure relief will be provided in the receiver fluid supply and discharge lines. The receiver will be designed for 150% of the fluid system design pressure.

Overtemperature and low-flow alarms will be provided for the absorber assembly.



### Operational Safety Procedures

Protective clothing (flame proof with face shield and hard hat) will be required for any inspection or maintenance procedure with the receiver system at high temperature. Rubber gloves and chemical safety goggles will be worn during any maintenance or installation procedure on the cold receiver system (pipe cutting, valve packing replacement etc.) which could involve the release of solid HTS.

# A.3.4 Collector Subsystem Requirement - Tower Assembly

### A.3.4.1 Design and Performance Requirements

### Overall Subsystem

The tower assembly includes the basic tower structure, supporting guy wires, foundations, working platforms, service elevator and ladders, lights, lightning protection, heliostat alignment target, electric power lines, and supports for heat transfer fluid lines, nitrogen purge lines, instrumentation lines and pneumatic lines. The primary function of the tower assembly is to provide support for the receiver subsystem. The baseline design approach shall be a constant cross-section steel tower with four guy cables strung at 45° angles to the tower. Overall design requirements for the 3.5, 4.5 and 6.5 year startup programs are listed below.

	3.5 Year	4.5 Year _	6.5 Year
Tower Height, m (ft)	40 (131)	40 (131)	40 (131)
Dry Receiver Weights, kg (1b)	7,950 (17,500)	7,230 (15,900)	6,450 (14,200)
Wet Receiver WEights, kg (1b)	10,000 (22,000)	9,100 (20,000)	8,500 (18,700)
Receiver Face Area m <sup>2</sup> (ft <sup>2</sup> )	22 (240)	21 (230)	20 (220)
Deflection Limits During Operation, mm (in)	150 (6)	150 (6)	150 (6)

Environmental requirements for tower design are specified in Section A.3.1.3.



### Tower Structure

The tower structure shall be constructed using commercial steel structure and drag bracing with angle depth and width to accommodate specific local load conditions. Tower cross-section shall be constant over the total height of the tower. The tower shall be assembled from prefabricated sections and supported by at least four guy wires.

# Guy Wire Supports

Four guy cables strung at a 45° angle shall be used to support the tower. The cabling shall be of commercial galvanized bridge cable type with the diameter determined on the basis of loads associated with the maximum overturning moment conditions. Tower sway limits are 150 mm (6 in).

#### Foundations

The tower foundation shall be a mat design of sufficient area to distribute the compressive load at a rate less than the soil bearing strength limit of  $7322 \text{ kg/m}^2$  (1500 lb/ft<sup>2</sup>) at a 2-ft depth. The guy wire foundations shall consist of buried concrete piers which are sized to accommodate the maximum cable loads.

#### Working Platforms

A working platform shall be constructed at the top of the tower with adequate space for personnel operations plus equipment need for receiver installation, inspection, maintenance and other services. The platform will include appropriate safety provisions such as guard rails and tiedowns in accordance with OSHA regulations.

#### Ladders

A caged access ladder with intermediate platforms shall be provided in accordance with OSHA requirements.



### Service Elevator

For the engineering experiment tower, a service elevator from ground level to the working platform shall be provided that has a load capability sufficient for multiple personnel plus small lightweight equipment. The elevator shall be provided with stops at any intermediate level for maintenance and repair as required. No provisions are to be made for a crane. A truck crane or helicopter shall be used to lift large items to the top of the tower.

### Lights

Lights shall be provided for necessary personnel operations and safety at the tower base, along the ladder and at the working platforms. In addition, aircraft warning lights shall be incorporated in accordance with FAA regulations. White, high-intensity lights will be mounted at the highest point of the receiver and tower structure. Safe access will be provided to each light to facilitate maintenance.

### <u>Lightning Protection</u>

The tower shall be shielded from lightning strikes by air terminals (masts) projecting above the top of the receiver. The terminals will be grounded with copper cables insulated from the tower with porcelain insulators.

### <u>Heliostat Alignment Target</u>

A target will be mounted on the side of the tower immediately below the top of the tower facing the heliostat field. This device is an inactive flat surface nominally  $4 \text{ m} \times 4 \text{ m}$  (13 x 13 ft) with a white diffuse reflecting surface.

### Electric Power Lines

Electrical outlets, cables and junction boxes will be included to provide 240-V power at the tower working platform for servicing operations, service



elevator and other necessary equipment. In addition, 115-V AC convenience outlets will be provided for small hand tools, lighting, and other small power accessories.

#### Interconnects and Supports

Miscellaneous structural attachments shall be provided for components of other subsystems including heat transfer fluid piping, nitrogen purge lines, vent lines, pneumatic control lines, and instrumentation and control conduits.

A.3.4.2 Operational Requirements

(Not applicable to tower assembly.)

A.3.4.3 Fabrication and Installation Requirements

### Manufacturing and Assembly

The tower will be constructed of standard steel structural members that are welded or bolted, as appropriate. Segments of the tower structure shall be prefabricated and transported to the plant site for final assembly. All steel members shall be painted for environmental protection and for site aesthetics.

# Transportation and Handling

Prefabricated tower segments must be transportable by truck.

# Field Installation

Prefabricated tower segments shall be installed at the plant site by crane. Segments may be bolted or welded as appropriate. Component installation shall be conducted after tower erection.



### Checkout and Adjustment

Tower base attachments and guy wire adjustments for tower alignment shall be accomplished during field installation.

#### A.3.4.4 Maintenance and Repair Requirements

### Reliablity/Availability

Tower structural life shall exceed 30 years. Tower components should be designed so as to operate satisfactorily without causing power plant shutdown at any time. Necessary maintenance shall be conducted during nonoperating plant periods or on a noninterference basis with plant operation.

#### Maintenance Procedures

Tower components, such as lights, electrical connections, service elevation, lightning rods, and interface connections should be readily accessible for periodic inspection and maintenance. Preventive maintenance including tower cleaning, painting, continuity and functional checks shall be periodically performed during nonoperating plant periods.

#### Spares and Interchangeability

There are no requirements for spares except for such common items as wiring connectors, attachment bolts, pipe hangers and support brackets.

### Maintenance Equipment

No major maintenance equipment is required at the site for the tower subsystem. Special portable working platforms with protective railings will be required for inspection and servicing of the receiver subsystem, energy transport subsystem (riser and downcomer piping, insulation and trace heaters), and tower elements.



#### A.3.4.5 Safety Requirements

### Equipment Design and Materials

Design stresses for the tower and guy wire supports shall not exceed the maximum allowed by standard tower building codes. No combustible materials shall be used in the tower subsystem.

### Safety Features and Warning Devices

Working platforms, ladder and service elevator shall be designed with protective railings. Portable platforms shall have suitable tie-downs or structural supports for safe manned servicing operations.

## Operational Safety Procedures

Hard hats will be required for any inspection or maintenance procedure in the vicinity of the tower. Safety harnesses shall be used by personnel for servicing operations in potentially dangerous positions on the tower.

### A.3.5 Energy Storage Subsystem Requirements

## A.3.5.1 Design and Performance Requirements

### Overall Subsystem

The thermal storage subsystem is required to store energy so that power generation can be continued during periods of little or no insolation. It must also act as a buffer to eliminate the effects of solar transients on the power conversion subsystem. The thermal storage capacity is based on a system capacity factor of 0.4. On a yearly basis, considering system heat losses and availability, the turbine demand was established relative to absorbed power requirements for Barstow insolation. The storage requirement was then determined from the spring equinox. The storage capacity is the integral under the power curve above the turbine demand line. The storage subsystem is therefore sized to accommodate the surplus energy on the day in which the maximum excess is expected.

A convenient way of relating turbine demand to the collector subsystem capability is through the solar multiple parameter which is defined as the ratio of the peak power collection capability to the turbine demand for 100% of rated output.



In addition to storing surplus thermal energy, the storage capacity was increased by 10 min of rated operation to buffer out receiver-induced transients. The total required thermal storage capacity expressed as MWHt can be calculated as follows:

$$Q_{s} = \frac{(T_{s} + T_{b})P_{r}}{\eta_{c}}$$

where

 $Q_e$  = Storage capacity, MWHt

 $T_s$  = Minimum storage at rated output, hr

 $P_n = Plant rated output, MWe$ 

 $\eta_{c}$  = Gross cycle efficiency

 $T_h = 10$ -min buffer period

Storage requirements for the various program durations are shown in Table A-4.

# Storage Tanks

3.5/4.5-Year Programs - Two storage tanks are required, each of which must be capable of containing the entire inventory of the Hitec storage media. One tank must be structurally designed to operate at the maximum fluid temperature and the other at the minimum fluid temperature. Both tanks will be mounted outside in a horizontal position at a level such that the molten salt can be drained by gravity from the remainder of the system into the tanks. Operation at temperatures below 454°C allow the use of carbon steel, but stainless steel is required to prevent corrosion at higher temperatures. Approximately 15 cm should be allowed between the maximum fluid level and the pump flange. The



TABLE A-4. Energy Storage Subsystem Requirements

	3.5 Year	4.5 Year	6.5 Year
Storage Technique	Two-Tank	Two-Tank	Thermocline
Temperature Range (°C)	260-454	288-510	288-538
Capacity (MWHt)	17.1	14.9	12.5

tanks must also be designed to withstand pressures exerted by the nitrogen cover gas at the maximum operating temperature. Each tank will have a salt fill port and drain as well as a relief valve and rupture disc. Tank diameters will be limited to 3.6 m by transportation constraints.

6.5-Year Program - One storage tank is required with a storage capacity of 12.51 MWHt. The inventory will be increased by 10% to allow for the thermocline thickness and an additional 9% volume excess will be provided for manifolds and ullage space. The vessel will be stainless steel and structurally designed to withstand stresses exerted by a mixture of rock and HTS undergoing temperature cycles between 288°C and 538°C. The tank must be vertically mounted outside and possess a length/diameter ratio greater than 1.5

# Storage Media

Hitec will be utilized alone as the storage medium in the 3.5 and 4.5-year programs. The 6.5-year program will require a heat transfer salt and iron ore mixture in which the solid will have a void fraction of 40%. The quantities of storage media will be determined based on the storage requirement (Table A-4) plus a 10% excess to make up for the thermocline thickness in the 6.5-year system. The Hitec (HTS) free surfaces will be blanketed with a nitrogen cover gas.

# **Insulation**

To minimize heat losses, all tanks operating below 454°C will be insulated with a fiberglass type material equipped with a weather cover. For operation at temperatures greater than 454°C, felted, spun mineral fiber will be used.



### Heaters

Tanks will be equipped with immersion heaters to be used to melt the Hitec during initial startup operations and following extended shutdown. The heaters should also be capable of maintaining the salt temperature above 171°C (3.5- and 4.5-year programs) and 260°C (6.5-year program).

# Gaseous Nitrogen Supply

High-pressure gaseous nitrogen equipment shall be provided to supply an inert environment for the storage tanks to prevent oxidation of the salt. Pressure regulators, check valves, and relief valves will be included in the design. The system shall be capable of maintaining the storage tank ullage at a minimum pressure of 6 psig.

### Site Preparation and Foundation

The site provided for tank installation in the two tank system will be excavated to a depth such that the tops of the tanks, when mounted, are below the level of the bottom of the steam generator to allow for gravity drain. The foundation can be dry soil of adequate bearing strength. For the dual media thermocline storage tank, a nonreinforced low density concrete foundation shall be provided which is contoured to the conical tank bottom. Excavation depth will depend on site soil conditions and the weight of the storage tank.

### Fluid Interfaces

3.5/4.5-Year Program - Bolted flanges will be provided on the upper surface of both tanks for the attachment of the pump cover plates. A nozzle will be located on the upper side of the cold tank shell for the steam generator return line and the receiver startup and drain line. A nozzle will be located in a similar fashion on the hot tank for connection of the receiver downcomer and transfer line. This line shall extend to the bottom of the tank.



6.5-Year Program — A nozzle on the upper manifold extending through the shell will be provided for connection of receiver downcomer and the steam generator feedline.

The bottom manifold will allow connection of the receiver feed pump intake line and steam generator return line.

Provision for attaching the gaseous nitrogen lines to the upper surfaces of all storage tanks will be provided, as well as salt fill ports.

### Instrumentation and Control

Connections will be provided on the storage tank walls at various locations for thermocouples, pressure transducers, and liquid level indicators.

### A.3.5.2 Operational Requirements

### Startup Mode

3.5/4.5-Year Program - The cold tank must supply Hitec at the minimum operating temperature to the receiver and act as a receptacle for the same flow until the fluid exiting the receiver reaches the specified operating temperature. The cold tank and hot tank must supply Hitec at the minimum and maximum operating temperature, respectively, to the steam generator until the equipment has warmed to acceptable operating temperatures. The cold tank must act as a receptacle for the entire flow.

6.5-Year Program - HTS in the lines is recirculated through the receiver and inventory from the tank is not required. HTS is required from both the top and bottom manifolds for steam generator warmup.

#### Normal Operation

3.5/4.5-Year Program - During normal operation the hot tank must accept Hitec flow from the receiver at the maximum operating temperature and simultaneously supply Hitec to the steam generator at the same temperature. The cold tank



will accept flow returning from the steam generator at the minimum operating temperature while supplying fluid to the receiver at the same temperature. The hot tank must be capable of supplying Hitec through the steam generator until the entire usable inventory has been transferred to the cold tank.

6.5-Year Program - The storage tank must receive and supply HTS through the top manifold at 538°C while accepting and supplying HTS through the bottom manifold at 288°C.

The storage tank must be capable of supplying HTS at  $538^{\circ}$ C to the steam generator until the thermocline reaches the top manifold and the outlet temperature drops to  $530^{\circ}$ C.

### Intermittent Mode

During cloud passage, operation will continue as normal except that a minimum flow from the receiver will be directed to the cold storage inlet.

#### Normal Shutdown Mode

When the steam generator feed pump is shut down, fluid from the lines will drain back into the tanks. There are no other requirements on the storage tanks in this mode.

### Emergency Shutdown Mode

If abnormal conditions are detected in the system, causing the feed pumps to be shut down, appropriate action will be taken by the plant operator. The tanks can be pressurized, vented, heated internally, or fluid can be transferred from one tank to another, if required.

#### Standby Mode

In the standby condition for emergency or normal repair operations, the immersion heater in the cold tank will maintain the salt at the minimum



operating temperature and the hot tank will be allowed to cool down through normal heat losses. If the shutdown duration is sufficiently long to allow fluid in the hot tank to cool substantially, the fluid in the hot tank can be pumped to the cold tank and maintained at the minimum operating temperature. For the vertical storage tank (6.5-year program), the immersion heater will maintain the HTS at 288°C.

#### Extended Shutdown Mode

For extended periods of shutdown, the immersion heaters may not be used and the storage tanks must be capable of retaining the entire inventory of salt in the solid state.

### A.3.5.3 Fabrication and Installation Requirements

### Manufacturing and Assembly

All tanks shall be shop fabricated using standard, proven manufacturing processes. Manifolds in the dual media thermocline tank are to be installed during tank construction.

# Transportation and Handling

Tank diameter and length will be limited such that the vessel can be shipped by truck and rail.

#### Field Installation

Wear plates and saddles will be welded to the horizontal storage tanks at the factory and labor required to locate the tank will be minimal although an adequate crane must be available. Insulation will be installed at the site. Provision for adding iron ore and/or salt to the tanks will be required. Salt added to the dual media system will be in a liquid state.



# Checkout and Adjustment

Tanks will be hydrotested at the factory. Instrumentation will be subjected to pre-operational testing following installation. Tanks will be rechecked for leaks during the initial addition and melting of the salt.

#### A.3.5.4 Maintenance and Repair Requirements

### Reliability/Availability

Design, fabrication, and checkout procedures should be used which will maintain a high level of storage tank reliability/availability so that forced and scheduled maintenance can be held to a minimum. Close tolerances on the purity and composition of the heat transfer salts should be maintained so as to minimize deviation from expected fluid properties.

#### Maintenance Procedures

Major repair of the storage tanks such as welding repair of a leak will require draining the affected tank. This is easily accomplished in the two tank system by transferring salt from one tank to the other. In the single tank system, the HTS will have to be drained and transferred to temporary storage or disposed of. Instrumentation, vent valves, and heaters must be periodically checked by calibration techniques. Preventative maintenance of the storage subsystem will include visual inspection of tanks for leaks or settling and inspection of the insulation for heat leaks and spalling. Composition of the salt shall be checked periodically by freezing point tests on samples from the system.

# Spares and Interchangeability

With the exception of instrumentation, no provision is made for spare tanks. Additional requirements for salt will be ordered as needed. Sufficient tanks of  ${\rm GN}_2$  will be kept on hand to ensure availability and will be replaced as necessary.



## Maintenance Equipment

No major maintenance equipment is required at the site. Calibration equipment for instrumentation must be available.

#### A.3.5.5 Safety Requirements

### Equipment Design and Materials

Design stresses for the steel used in tank fabrication shall not exceed the maximum allowed by the ASME Boiler Code. The salt is nonflammable but is an oxidizer and will support combustion of other materials. Noncombustible materials will be used where possible. Contamination of the site will be minimized by washing with water.

## Safety Features and Warning Devices

Pressure relief valves will be provided on all storage tanks, as well as rupture discs. Over temperature alarms will be provided on tank temperature sensors.

## Operational Safety Procedures

Persons handling Hitec at room temperature should exercise care to avoid accidental ingestion or contact with eyes or skin. Food should not be permitted in any area where contamination with even small amounts of Hitec could occur. Exposure can be minimized by wearing rubber or plastic-coated gloves and chemical safety goggles. Wash thoroughly after handling. Operating personnel should wear clean uniforms; cloth impregnated with Hitec has increased flammability and can be irritating to the skin.

Molten Hitec presents the same hazards noted above for Hitec at room temperature. In addition, its sensible heat can cause burns. Wear flameproof clothing, face shield and hard hat during any procedure which might cause spattering of a molten salt bath or when maintaining or repairing hot storage tanks.



# A.3.6 Energy Transport Subsystem Requirements

### A.3.6.1 Design and Performance Requirements

#### Overall Subsystem

The energy transport subsystem is divided into two independent loops. The receiver loop is required to transport fluid from the receiver at the maximum system operating temperature to the thermal storage subsystem and return fluid from storage to the receiver at the minimum operating temperature. The steam generator loop is required to transport fluid from the storage subsystem at the maximum operating temperature to the steam generator and return fluid from the steam generator to the storage subsystem at the minimum operating temperature. Separate pumps are required for each loop and flow is remotely controlled to achieve the desired temperature requirements shown in Table A-5. Peak power and flowrate requirements are also shown in the table.

TABLE A-5. Energy Transport Subsystem Requirements

	3.5 Year	4.5 Year	6.5 Year
Fluid	Hi tec	Hi tec	HTS
Peak Receiver Power (MWt)	7.08	6.05	4.87
Steam Generator Power (MWt)	4.24	3.58	2.83
Receiver Flow Rate (kg/hr)	83,950	62,770	44,920
Steam Generator Flow Rate (kg/hr)	50,280	37,150	26,100
Receiver Temperature			
Inlet (°C)	260	288	288
Outlet (°C)	454	510	538
Steam Generator Temperature			
Inlet (°C)	454	510	538
Outlet (°C)	260	288	288

### Major Components

# Piping

In general, pipe lines will be required to transport Hitec in the following major loops:

- Receiver Riser From the receiver feed pump discharge to the receiver inlet (40 m elevation).
- Receiver Downcomer From the receiver exit to the storage tank.

  The line will terminate in the hot tank (3.5/4.5 year) or in the upper manifold of the dual media storage tank (6.5 year program).
- Steam Generator Feedline From the steam generator feedpump discharge to the steam generator entrance.
- Steam Generator Return Line From the steam generator exit to the storage tank. The line will terminate at the cold tank nozzle on the upper shell (3.4/4.5-year program) or at the lower manifold on the dual media storage tank (6.5-year program).

The following piping segments are required to complete minor piping loops indicated below. The line name indicates its function.

- Receiver Startup and Drain From the receiver downcomer (ground level) to the cold tank entrance nozzle.
- Steam Generator Startup From the receiver riser (ground level) to the steam generator feed line (mixer).
- Transfer Lines From the steam generator feedline to the return line and from the receiver downcomer (at the storage tank entrance) to the receiver riser at the pump discharge.

Velocity in the lines is limited to 3 m/s and any lines exposed to temperatures greater than  $454^{\circ}\text{C}$  will be stainless steel.

#### Pumps

Two centrifugal pumps are required to circulate molten salt in the various circuits. They may be identical pumps operated at different speeds but must



be capable of operating at elevated temperatures (given in Table A-5) and seal against salt leakage. The receiver feedpump must be capable of pumping salt to the receiver and back to the storage subsystem at the maximum flowrate indicated in Table A-5. The steam generator feedpump must be capable of pumping salt to the steam generator and back to the storage subsystem at the required flow rate. The submerged pumps must be able to backspin without damage as fluid drains back through the discharge following shutdown. Pumps for the 6.5-year program are to be horizontal in line.

#### **Valves**

Remote controlled shutoff valves are required to control flow in the receiver and steam generator loops. A remote control valve is required in the steam generator feed line to adjust the flowrate such that the steam generator outlet temperature is within required limits. A remote control valve is required in the steam generator startup line to control flow of low temperature salt as the steam generator is warmed up.

The remotely operated control valve located at the base of the receiver down-comer must be capable of serving two functions. Primarily, it must control the flowrate such that the receiver outlet temperature is within required limits. Secondly, it must dissipate the hydrostatic head from the receiver downcomer to prevent overpressuring the storage tank. Two hand valves are required in the transfer lines.

All valves must be capable of operating at elevated temperatures (Table A-5) without leakage.

### Insulation

All pipes and valves will be insulated with a high temperature, calcium silicate insulation to minimize heat losses and require a sealed weather cover.

### Trace Heaters

Trace heaters are required on all lines and valves. They must be capable of maintaining component temperatures above 171°C (3.5- and 4.5-year programs) and 260°C (6.5-year program) to prevent salt from freezing in the lines. The heaters must be firmly attached and capable of withstanding elevated temperatures.

### Structural Interfaces

Physical interfaces are described in Section 3.6.1.2 under Piping. Welded pipe connections should be used when possible and ring joint flanges used otherwise.

### Instrumentation and Control

Connections will be provided on lines, as required by the control system, for the purpose of transmitting temperature, pressure, flowrate, and valve position.

#### A.3.6.2 Operational Requirements

#### Startup Mode

#### Receiver Loop

Temperature sensors will be checked to assure that liquid conditions exist at the pump impeller. The receiver feedpump will be started to circulate salt through the receiver and back to the cold tank (or bottom manifold of the dual media tank) until the receiver outlet temperature is within required limits. Flow will then be switched to the hot tank (or top manifold of the dual media tank).

### Steam Generator Loop

Following the receiver warmup period, the steam generator feedpumps will be turned on and flow from the cold tank (or bottom manifold of the dual media tank) will be diverted to the steam generator feedline to mix with salt flowing from the hot tank (or top manifold of the dual media tank). The appropriate flow valves will be regulated such that the fluid temperature at the steam generator increases slowly from the minimum to the maximum operating temperature.

### Normal Operating Mode

### Receiver Loop

During normal operations, the receiver feedpump must supply salt to the receiver with flow being controlled to keep the receiver outlet temperature within required limits. Fluid will be returned to the hot tank (or top manifold of the dual media tank).

## Steam Generator Loop

Fluid conditions will be monitored at the steam generator outlet and flow from the steam generator feedpump will be controlled to maintain rated temperatures there. The salt will be returned to the cold tank (or bottom manifold of the dual media tank). When insolation is inadequate such that flowrate from the receiver feedpump drops below 10 percent of the rated output, it will be shut down. Operation of the steam generator can continue until storage is depleted.

#### Intermittent Mode

During intermittent cloud passage, normal operation will continue until the flowrate in the receiver loop has been reduced to 10 percent of the rated flow. At this time, flow will be maintained at this level and returned to the cold storage inlet. Flow can be continued in the steam generator loop until the hot tank has been emptied (or the thermocline reaches the upper manifold in the dual media tank).



#### Normal Shutdown Mode

### Receiver Loop

The receiver feedpump will be shut down when the flowrate has dropped to 10 percent of the rate capacity and the receiver doors have closed. Salt will partially drain from the lines back into the storage tank. Trace heating will be initiated when line temperatures reach 171°C (288°C for 6.5-year program).

### Steam Generator Loop

The steam generator feedpump will be shut down when the level indicator shows the hot tank to be empty (or when the outlet temperatrue from the dual media tank upper manifold falls below spec). Trace heating will be initiated when line temperatures reach 171°C (288°C for 6.5-year program).

### Emergency Shutdown Mode

If abnormal conditions are monitored in the system, both loops will be shut down until the problem is located and corrected.

### Standby Mode

In the standby mode for repair, pumps will be shut down with the receiver doors closed. Trace heating of the lines will be initiated if required.

#### Extended Shutdown Mode

In this mode, both pumps are turned off and trace heaters may not be used. Liquid remaining in the lines is purged to the storage tanks. The pumps must be able to withstand solidification of the salt.



### A.3.6.3 Fabrication and Installation Requirements

### Manufacturing and Assembly

All lines, pumps, and valves shall be fabricated using standard, proven manufacturing processes.

### Transportation and Handling

No special transportation problems are envisioned.

### Field Installation

Following tower erection, receiver assembly, and tank emplacement, all lines, valves, and pumps will be installed at the site. Trace heaters, instrumentation, and insulation will also be field installed.

### Checkout and Adjustment

Pumps will be flow-tested with water at the factory. Lines and valves will also be pressure-tested and leak checked prior to assembly. Trace heaters will be checked following installation before insulation is wrapped.

#### A.3.6.4 Maintenance and Repair Requirements

# Reliability/Availability

Design, fabrication, and checkout procedures should be used which will maintain a high level of component reliability. Failure modes which should be minimized are line leaks and clogging, valve shaft seal leaks, and failure of pump bearings and seals.



### Maintenance Procedures

Major repair of lines such as welding repair will require draining the affected lines. Instrumentation, valves, and heaters must be periodically checked by calibration techniques. Preventative maintenance will include visual inspection of lines, valves and pumps for leaks. Pumps must be lubricated and checked for corrosion. Insulation must be inspected for heat leaks and spalling.

# Spares and Interchangeability

Pumps are similar so that one spare can be kept on hand as well as gaskets. The pumps must be able to be unbolted at the cover plate and lifted from the tank. Spare sensors, valves, and flowmeters will be stocked (one of each type and size). Soft metal gaskets for (ring joint) flanges will be kept in stock.

### Maintenance Equipment

A crane will be required for lifting pumps from the storage tanks. Provisions must be available for maintaining or repairing the receiver riser and down-comer. Calibration equipment for instrumentation must be available.

#### A.3.6.5 Safety Requirements

## Equipment Design and Materials

Pipe wall thicknesses will be sized according to the ANSI code. Contamination on the site will be minimized by washing with water. The use of combustible materials will be minimized.

# Safety Features and Warning Devices

Over temperature alarms will be provided for critical temperature sensors.

Pressure relief will be provided in the receiver assembly. Provision will be



made to contain any salt leakage. The system will automatically shut down at the detection of a safety hazard.

### Operational Safety Features

Automatic operation of the system will only require personnel proximity to the transport system during maintenance. Precautions to be observed when contact with the salt is possible were already described.

### A.3.7 Power Conversion Subsystem Requirements

### A.3.7.1 Design and Performance Requirements

### Overall Subsystem

The function of the power conversion subsystem (PCS) will be to convert the thermal energy stored in the Hitec/HTS fluid into 1000 kWe net of 60 Hz electrical power. The output of the PCS shall be regulated suitably for integration into an existing electrical power system network. The PCS shall consist of:

- A. Steam generator, steam supply header, valves and controls
- B. Steam turbine
- C. Electrical generator
- D. Surface condenser and air removal equipment
- E. Feedwater return piping, pumps, valves, heaters and controls
- F. Water treatment equipment and wastewater pond
- G. Plant auxiliaries
- H. Emergency power supply
- I. Electrical connections, cabling, meters, relays, switchgear, Transformers, controls

### Turbine/Generator and Accessories

The turbine/generator shall be a multi-stage, high speed, high efficiency machine geared to 1800 rpm, capable of accepting steam at pressures and



temperatures given in Table A-6 and expanding the steam of 0.083 bars (2-1/2 inches Hg Abs) condenser pressure. Uncontrolled extraction will be possible with the number of extractions listed in Table A-6. The machine will be capable of producing the electrical power listed in Table A-6 with steam at rated conditions. Accessories to be supplied with the turbine include:

Control system complete with all stop and trip valves and control valves, emergency overspeed governor; protective devices; supervisory instrumentation; gear-driven oil pump, motor-operated oil pump; lube oil reservoir, coolers and filters; sheet metal lagging and insulation.

The generator shall be a gear driven, 1800 rpm, four pole unit capable of producing 1400 KVA, 0.8 power factor, 4160 volts at 60 Hz.

### Steam Generator

The steam generator shall consist of a preheater, natural recirculation type boiler and a superheater capable of supplying steam at pressures and temperatures given in Table A-6. Steam will be generated on the tube side of the heat exchangers with salt contained in the shell. Immersion heaters will be provided to prevent freeze-up of the salt. The thermal duty of preheater, boiler and superheater sections is given in Table A-7.

#### Deaerator

The deaerator shall be a vertical tray-type direct contact heater capable of reducing oxygen level of 0.007 cc/liter at rated conditions. It shall also have a storage capacity equivalent to 10 min at full flow.

TABLE A-6. Turbine Conditions

	3.5-Year	4.5-Year	6.5-Year
	Axial	Axial	Radial
Inlet Temperature, °C (°F)	.427	482	510
	(800)	(900)	(950)
Inlet Pressure, bars (psia)	62	103	121
	(900)	(1500)	(1750)
No. of Extractions	1	1	5
Power Level, kWe	1,135	1,110	1,080

TABLE A-7. Steam Generator Requirements

Program	3.5 Year	4.5 Year	6.5 Year
Preheater Duty, MWt	0.89	1.00	0.50
Boiler Duty, MWt	2.67	1.75	1.47
Superheater Duty, MWt	0.68	0.83	0.86
Feedwater Inlet Temperature, °C (°F)	163 (325)	163 (325)	243 (470)

### Closed Feedwater Heaters

Closed feedwater heaters shall be designed to have sufficient heat transfer area to efficiently transfer heat at the required rate with a 2.8°C terminal difference and a 5.6°C drain cooler approach. Thermal duty requirements of the closed feedwater heaters are given below:

6.5-Year Program Only

Heater		• -	Duty
LP	No.	1	145 kWt
LP	No.	2	80 kWt
HP	No.	4	193 kWt
HP	No.	5	294 kWt

### Heat Rejection Equipment

Heat rejection shall be accomplished using a surface condenser and wet cooling tower. An ambient wet bulb temperature of  $23^{\circ}\text{C}$  ( $74^{\circ}\text{F}$ ) and a condenser pressure of 0.083 bars (2.5 in HgA) is assumed for design purposes. Condenser tube material should be admiralty or a similar alloy.

#### Pumps

Pumps shall be selected on the basis of efficiency and reliability. Redundancy shall be provided where it is shown to be cost effective.



### Water Treatment Equipment

The makeup water demineralizer shall consist of a single train unit consisting of a cation exchange vessel, anion exchange vessel and mixed bed exchange vessel. Makeup water requirements for the steam loop will be between 0.38 and  $2.65 \text{ m}^3$  (100 to 700 gallons) per day.

A condensate polisher shall be provided in the form of a full-flow powdered resin unit.

A steam generator chemical feed system shall be provided capable of feeding hydrazine, an amine, and a boiler chemical. A cooling tower chemical feed system shall also be provided to feed sulphuric acid and a scale inhibitor to the circulating water.

### Electrical Plant Equipment

The turbine/generator shall be connected to the electrical network by a switch-gear unit. Connections from the generator to switchgear, and from switchgear to the electrical network, will be cable. Surge protection will be provided for the generator. An uninterruptable power source (UPS) shall be provided to supply power to the computer and turbine lubrication system.

Auxiliary power shall be provided by auxiliary transformers connected to the grid. They shall supply 480 V and 240 V to the necessary auxiliaries.

A diesel engine generator shall provide power during emergencies and for off-grid startup and shutdown. The generator will be rated at either 45 kW (for emergency shutdowns and standby only) or 125 kW (for off-grid startups).

#### Structural Interfaces

A structural interface shall exist between the PCS and the ETS where the ETS steam generator feed and return lines carrying Hitec/HTS meet the steam generator.



### Fluid Interfaces

A fluid interface shall exist between the PCS and the ETS where Hitec/HTS is inlet to the steam generator from the steam generator feedline and returned to the ETS via the steam generator return line.

### Electrical Power Interfaces

Electrical power interfaces shall exist with the energy transport, plant control, tower, receiver and concentrator subsystems. These interfaces shall supply power to the subsystems during both normal and emergency conditions.

### A.3.7.2 Operational Requirements

### Startup Mode

It will be necessary to follow a startup procedure once every day. This will begin with a number of power conversion subsystem prestart checks. Following these checks, warmup of the steam generator will begin, condenser vacuum pump will begin to extract nitrogen blanket gas, and cleanup of the feedwater heating loop will begin. When steam has reached the appropriate conditions, turbine runup shall begin followed by application of load. Procedures shall be designed for both rapid start-up and long life of subsystem components.

#### Normal Operating Mode

Under normal operating conditions, the flow rate of Hitec/HTS to the steam generator will be modulated to provide steam sufficient to supply the demand electrical load.

#### Intermittent Mode

The operation of the PCS is unaffected by cloud passage, therefore, no action is required during this occurrence.



## Normal Shutdown Mode

This mode will occur every day when the power conversion system is shut down and expected to be started up the next day. Load shall be removed from the turbine and turbine shall be stopped. Hitec/HTS flow to steam generator shall be stopped with salt remaining in the steam generator. The vacuum in the condenser shall be broken using nitrogen gas and nitrogen shall be used to blanket the feedwater heating tray as it cools. Trace heating of the steam generator shall begin (if required).

### Emergency Shutdown Mode

This mode will occur only when abnormal operation of the power conversion subsystem is detected. Instrumentation shall sound alarms when abnormal conditions are detected. The plant operator will then determine if remedial action is possible or if immediate shutdown is needed. If so, the turbine emergency stop valve shall be closed and load removed from turbine. Hitec/HTS flow to the steam generator shall be stopped and excess steam vented to atmosphere. After the emergency turbine stop, normal shutdown procesures will be followed as completely as is possible.

#### Extended Shutdown Mode

Extended shutdown with all component temperatures reduced to ambient conditions, may be required for prolonged adverse weather conditions, and will be required for maintenance or repair of some components. This mode will be identical to the normal shutdown mode with the exception that the Hitec/HTS will be drained from the steam generator to storage and replaced by gaseous nitrogen. In some cases, the water in the subsystem may also be partially or completely drained and replaced by nitrogen.

# A.3.7.3 Fabrication and Installation Requirements

## Manufacturing and Assembly

Manufacturing planning for the experimental plant will be based upon small production runs (1-10 units) and use of standard off-the-shelf equipment where possible. Factory assembly and testing and skid-mounting will be used whenever possible to minimize on-site assembly.

## Transportation and Handling

All components, including the skid-mounted turbine/generator and steam generator, must be transportable by truck and rail. Transportability limits are given in Section A.3.1.7.

### Field Installation

Components shall be factory assembled and skid mounted to as large as extent as possible. Components and piping will be bolted or welded as appropriate at the site.

#### Checkout and Adjustment

Turbine, generator, steam generator, and other major components shall be tested at the factory before shipment. Testing and adjustment of components shall be conducted on-site when necessary.

#### A.3.7.4 Maintenance and Repair Requirements

# Reliability/Availability

The steam turbine, steam generator and other major components of the PCS shall be checked and tested to as large a degree as possible at the factory before shipment.



### Maintenance Procedures

A schedule of periodic maintenance measures shall be followed to ensure the proper maintenance and function of all elements of the PCS. This will include: visual inspections, analysis of lubricant and water condition, lubrication of components and periodic dismantling of components to check for wear.

### Spares and Interchangeability

Spare components will be stocked where it is determined to be cost effective.

### Maintenance Equipment

An overhead crane or monorail will be provided to assist in maintenance of major components. A source of compressed air will also be supplied for use with penumatic tools. Calibration equipment must be available to periodically calibrate instrumentation.

### A.3.7.5 Safety Requirements

## Equipment Design and Materials

The PCS shall be designed to minimize safety hazards to operating and service personnel, the public, and equipment. Design stresses for the steam generator and piping shall meet the applicable ASME codes, and all other applicable standards, regulations and codes shall be complied with in the design and construction of the plant.

### Safety Features and Warning Devices

All elements of the PCS operating at elevated temperatures shall be insulated against contact with or exposure to personnel. Any moving elements shall be shielded to avoid entanglements and safety override controls/interlocks shall be provided for servicing. Electrical components shall be insulated and grounded. All pertinent OSHA rules and regulations shall be observed.



### A.3.8 Plant Control Subsystem Specifications

The plant control subsystem (PCS) will provide the facilities for the control and monitoring of the operating plant. These facilities, through automatic, semiautomatic, or manual operating methods, will perform the following functions:

- Control and command of the subsystems components (valves, motors, blowers, etc.) to establish and/or maintain plant stability through all phases of operation.
- Sense all subsystem operations to assess safe and proper operation of the plant.
- Display and/or record all sensed parameters in a form pertinent to the evaluation of plant performance, operation and safety.

These functions will accomplish the objectives of cost effectiveness, high reliability and simplicity of design and operation.

### A.3.8.1 Design and Performance Specifications

The PCS will accomplish the following major control and display tasks:

- Power Conversion
  - Turbine startup and shutdown in accordance with an optimum turbine life algorithm, automatically and/or by operator guidance menu. This will be accomplished by controlling inlet steam temperature rise rate, and controlling speed to limit excessive vibration dwell.
  - Coordinate load demand signals with turbine throttle and steam generator.
  - Monitor, display and alarm appropriate data.
- Energy Transport
  - Sequence all valves, set points, motors, etc., during startup, operation and shutdown.
  - Emergency sense and coordinate the shutdown of the concentrator.
  - Adjustment controller transfer function and set point as required.
  - Monitor, display and alarm appropriate data.



#### • Concentrator

- Sequence startup and shutdown.
- Track operational space and/or receiver coordinates
- Manage track modes, time, beam safety and alignment.
- Modulate power using partial field tracking techniques.
- Emergency sense, slew and stow heliostats.
- Monitor, display and alarm appropriate data.

#### Integration

- Coordinate the various subsystem control functions so as to optimize plant performance, reliability and safety.
- Minimize the operator's skill and training requirements.
- Monitor, display and alarm appropriate data.

The PCS will acquire, manipulate and record plant data used to evaluate plant maintenance requirements. These functions will be accomplished in a timely manner, correlated with events of plant operation, and logged in an interpretable form and retained.

## Functional Specifications

#### Power Conversion

The PCS will interface with the controls furnished with the turbine. The manual turbine controls will be integrated into the system control panel. The PCS interface will consist of discrete on-off signals to the T-GS, and temperature, pressure, speed, level, vibration power output and on-off signals from the T-GS for display to the operator and/or for use by the PCS. As the turbine is started and stopped at least daily, the fatigue life of the turbine shell will be considered and optimized using an algorithm furnished by the turbine manufacturer. The PCS will analyze turbine data and display instructions to the operator for proper turbine operation during startup and shutdown. The PCS will provide alarms on shell temperature, shell temperature rate, vibration, oil level, temperature and pressure, speed, load and other measurements as required.



# **Energy Transport**

PCS will control the receiver coolant flow so that it is properly routed in the system depending on its temperature. The PCS will sequence the on-off valves according to the operational requirements outlined in the energy transport description. The modulating valve will be controlled so that fluid entering the hot tank is maintained at the specified temperature, with short term fluid temperature transients due to insolation transient limits. Control topology will be selected considering coolant transport time, expected solar transients, receiver thermal characteristics, valve and instrumentation characteristics, and the hot fluid temperature tolerances.

Steam generator control will be accomplished as outlined in the operational specifications for energy transport and power conversion subsystems.

#### Concentrator

The PCS will include a three element controller for the concentrator. For the 3-5 year program this controller will be identical to that used for heliostat control for the 10 MWe system at Barstow. The control is such that maximum mirror normal pointing error for each axis will be 0.75 milliradian (one sigma) whenever the sun is at least 0.26 radian above the horizon.

### Instrumentation and Control List

Table A-8 gives the presently estimated number and types of instrumentation and control functions that will be used in the PCS.

#### A.3.8.2 Operational Specifications

Operation of the PCS will be primarily semiautomatic to minimize the skill level and work load requirements on the operator. By "semi-automatic" is meant that operations will be initiated, changed or terminated by the operator, with the details of operation implementation left to the control system. Thus receiver and steam generator startup will be operator initiated



TABLE A-8. Estimated Control and Instrumentation List

Subsystem	Position Control	Discrete Control	Temperature	Pressure	Flow	Level	Position Indication	Valve State	Volts	Атрѕ	Watts	VARS
Energy Transport	5	10	75				5	10				
Power Conversion	3	20	10	15	2	5	3	20	5	4	1	1
Concentrator	320						320					

and the necessary sequencing, timing, set-point controlling, alarming, etc., will be automatic. Operator override will be provided so that the operator can manually operate the plant (with certain practicality exceptions such as heliostat tracking).

Operator interface with the PCS will be through the control console. The interface will be designed so that a single operator can operate the plant at all times.

Access will be available to control, display and alarm of all plant controlled and/or instrumented functions. Set points, alarming levels, sequencing logic and timing will also be available for manipulation at the control panel.

# A.3.8.3 Fabrication and Installation Specifications

All of the PCS hardware will be off-the-shelf equipment.

The control console will be assembled and checked out in the factory to minimize field installation and development. Any new software will be integrated and debugged to the extent possible at this time.

Field installation will require interconnection of control elements, instrumentation and console. Complete subsystem integration and checkout will be accomplished at this time.

#### A.3.8.4 Maintenance and Repair

Where cost effective, PCS will use reliability/availability enhancing techniques, such as redundancy and environmental screening. The PCS will be highly modular so that troubleshooting and repair at the subsystem level is straightforward and quick. A cost effective amount of self check and failure indication will be built into the PCS hardware and software. Repair at the subsystem level will be by module replacement. Defective, replaced modules will be returned to the module vendor for repair, repaired on site or scrapped, depending on the cost effectiveness of each action.

Standard hand tools and electronic laboratory test equipment will be utilized to maintain equipment.

#### A.3.8.5 Safety Specifications

Personnel hazards in operation and maintenance of the PCS will be minimal and involve electrical shock hazard, instrument environment, etc. Designs shall meet all required codes, such as the National Electric Code, to eliminate hazard to the workers.

In its operation the PCS will intimately be involved in plant safety control and alarming. In such areas as solar beam control, receiver metal and coolant temperature, steam temperature and pressure, especially careful design attention will be provided to subsystem reliability. As previously mentioned, judicious use of reliability enhancement methods as well as careful and thorough subsystem analysis shall be used to optimize ability of the PCS to discharge its system safety responsibilities.